NAVAL FACILITIES ENGINEERING SERVICE CENTER
Port Hueneme, California 93043-4370

TECHNICAL REPORT
TR-2203-ENV

COST AND PERFORMANCE REPORT

VALIDATION OF THE LOW-RANGE DIFFERENTIAL PRESSURE (LRDP) LEAK DETECTION SYSTEM

by

Naval Facilities Engineering Service Center
Vista Engineering Technology

March 2002

Approved for public release; distribution is unlimited.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0811

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From – To)*
March 2002	Final	22 March – 08 June 2000

4. TITLE AND SUBTITLE

COST AND PERFORMANCE REPORT – VALIDATION OF THE LOW RANGE DIFFERENTIAL PRESSURE (LRDP) LEAK DETECTION SYSTEM

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Naval Facilities Engineering Command and Vista Engineering Technology

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSES

Commanding Officer
Naval Facilities Engineering Service Center
1100 23RD Avenue
Port Hueneme, CA 93043-4370

Vista Engineering Technology
755 North Mary Avenue
Sunnyvale, CA 94086

8. PERFORMING ORGANIZATION REPORT NUMBER

TR-2203-ENV

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Environmental Security Technology Certification Program
901 North Stuart Street, Suite 303
Arlington, VA 22203

10. SPONSOR/MONITORS ACRONYM(S)

ESTCP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Naval Facilities Engineering Service Center (NFESC) Port Hueneme, California, and its industrial partners, Vista Research, Inc., and Vista Engineering Technologies, L.L.C., have demonstrated and validated (DEM/VAL) an innovative mass-based leak detection system for bulk fuel underground storage tanks (USTs). The Low-Range Differential Pressure (LRDP) system is a computer-controlled system that can reliably detect small leaks in bulk USTs ranging in size from 50,000 gal to 12,500,000 gal. As part of this project, it has been evaluated for performance by an independent third party in a 122.5-ft diameter, 2,100,000-gal tank following EPA's standard test procedures. The LRDP meets monthly monitoring and annual precision (tightness) test regulatory compliance requirements using either a 10-h (overnight) or 24-h test.

The LRDP has several significant cost advantages over the internal and external technologies. The cost advantages are realized because of the extremely high performance of the LRDP and the probability of false alarm, the on-line monitoring capability of the LRDP when permanently installed in a tank, the capability of the system to conduct a short test (an overnight test), and the low recurring costs associated with testing.

The cost of a tracer method is expensive because of the high recurring cost of testing. The cost of other mass-based methods is high because of lower performance and the inability to meet both the monthly monitoring and annual precision regulatory requirements with an online system. In addition, the LRDP has the potential to save DOD many hundreds of millions of dollars in terms of clean-up and tank replacement cost avoidance.

15. SUBJECT TERMS

Environmental Security Technology Certification Program (ESTCP); leak detection; low range differential pressure (LRDP); demonstration and validation (DEM/VAL); underground storage tank (UST)

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UL	47	19b. TELEPHONE NUMBER *(Include area code)*

Table of Contents

Page

List of Figures v

List of Tables vi

Acronyms vii

Acknowledgments viii

1.0 Executive Summary 1

2.0 Technology Description 4

2.1 Technology Development and Application 4

2.1.1 Description 4

2.1.2 Testing Methods 6

2.2 Regulatory Requirements 7

2.3 Previous Testing of the Technology 8

2.4 Advantages and Limitations of the Technology 8

3.0 Demonstration Design 10

3.1 Performance Objectives 10

3.2 Selection of a Test Site/Facility 10

3.3 Site/Facility Characteristics 11

3.3.1 DEM/VAL 1: Point Loma Fuel Terminal (Third-Party Evaluation) 11

3.3.2 DEM/VAL 2: Hunter Army Airfield 11

3.4 Physical Set-up and Operation 12

3.4.1 DEM/VAL 1: Point Loma Fuel Terminal (Third-Party Evaluation) 12

3.4.2 DEM/VAL 2: Hunter Army Airfield 14

Table of Contents (cont.)

	Page
3.5 Sampling/Monitoring Procedures	16
4.0 Performance Assessment	17
4.1 Third-Party Evaluation Results for Bulk USTs	17
4.1.1 Point Loma Evaluation Test Results	17
4.1.2 Performance Estimates for a Single Test (LRDP-10 and LRDP-24)	18
4.1.3 Performance Estimates for More than One Test (LRDP-10-n and LRDP-24-n)	19
4.1.4 Summary of Performance Results for Different Size Tanks	20
4.1.5 How to Use the LRDP System	21
4.2 Results of the DEM/VAL of the LRDP in a 50,000-gal UST	22
5.0 Cost Assessment	24
5.1 Cost Reporting	24
5.2 Cost Analysis	24
5.3 Cost Comparison	26
6.0 Technology Implementation	29
6.1 Cost Observations	29
6.1.1 Cost Avoidance	29
6.1.2 Commercialization and Technology Transfer	30
6.2 Performance Observations	30
6.3 Scale-up	30
6.4 Other Significant Observations	31
6.5 Lessons Learned	31

Table of Contents (cont.)

Page

6.6 End-User Issues 31

6.7 Approach to Regulatory Compliance and Acceptance 32

7.0 References 33

8.0 Points of Contact 36

Appendix A - Results of the Performance Evaluation for Different Implementations of the LRDP-10 and LRDP-24 Leak Detection Systems A-1

List of Figures

Page

Figure 1. Low-Range Differential Pressure (LRDP) system for bulk USTs 4

Figure 2. Photograph of the in-tank portion of the LRDP system for a bulk UST with vertical walls 5

Figure 3. Tank 175 at the Point Loma Fuel Terminal 11

Figure 4. Installation of the LRDP in the Point Loma tank 12

Figure 5. Installation of the LRDP in the 50,000-gal UST at the Hunter Army Airfield....... 14

Figure 6. Top of the LRDP being installed in an 8-in.opening in a 50,000-gal UST at the Hunter Army Airfield. 14

Figure 7. Level data obtained with the LRDP-24 system for Test 10 17

Figure 8. Least-squares lines fitted to the test results of the LRDP-10 and the LRDP-24..... 17

List of Tables

Page

Table 1. Summary of the Four Methods of the LRDP System for Bulk Tanks 7

Table 2. Summary of the Test Results and Induced Leak Rates for the LRDP Systems at Point Loma 13

Table 3. Summary of the Test Results for the LRDP Systems in a 50,000-gal UST at Hunter Army Airfield 15

Table 4. Mean and Standard Deviation of the Difference between the Measured Leak Rates (Test Results) and Induced Leak Rates for the LRDP-10 and LRDP-24 18

Table 5. Estimates of the Minimum Detectable Leak Rate (MDLR) for the LRDP-10 and the LRDP-24 18

Table 6. Example of the MDLR in gal/h (P_D = 95% and a P_{FA} = 5%) as a Function of Tank Diameter 20

Table 7. Largest Diameter Tank in which a 0.20 gal/h Leak Rate Can Be Detected as a Function of the Number of Tests Averaged 20

Table 8. Largest Diameter Tank in which Various Leaks Can Be Detected as a Function of Target Leak Rate 21

Table 9. Estimate of performance for the LRDP made for 8-h and 24-h test duration in a 50,000-gal UST. 22

Table 10. Summary of the Costs of the Two DEM/VALs of the LRDP System. 24

Table 11. Compliance Monitoring Technology Costs for the LRDP on a Per Tank Basis.... 26

Table 12. Comparison of the Cost of Testing with Monthly Monitoring and an Annual Precision Test for Each Bulk UST for the First Year 28

Table 13. Comparison of the Cost of Testing with Monthly Monitoring and an Annual Precision Test for Each bulk UST Over 1, 3, 5 and 10 Years 28

Table 14. Comparison of the Cost of Testing with Monthly Monitoring and an Annual Precision Test for 15 bulk USTs Over 1, 3, 5 and 10 Years 28

Table 15. Points of Contact 35

Table A-1. Formula to Compute the Threshold and Target Leak Rate as a Function of Tank Diameter for the LRDP-10 .... A-1

Table A-2. Formula to Compute the Threshold and Target Leak Rate as a Function of Tank Diameter for the LRDP-24 .... A-1

Acronyms

Page

AST	Aboveground storage tank
CERF	Civil Engineering Research Foundation
CERL	Construction Engineering Research Laboratory (Army)
DESC	Defense Energy Support Center (DESC)
DoD	Department of Defense
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
EvTEC	Environmental Technology Evaluation Center
MDLR	Minimum Detectable Leak Rate
NAS	Naval Air Station
NFESC	Naval Facilities Engineering Service Center
NWGLDE	National Work Group on Leak Detection Evaluations
P_D	Probability of Detection
P_{FA}	Probability of False Alarm
P_{MD}	Probability of Missed Detect
PLC	Programmable Logic Controller
PSA	Product surface area
RTD	Resistance Temperature Device
TLR	Target Leak Rate
UST	Underground Storage Tank
VR	Volume Rate

Acknowledgments

The LRDP team would like to acknowledge and thank the fuel farm directors and their staff at the Point Loma Fuel Terminal, the Hunter Army Airfield, the Defense Energy Office, Los Angeles (San Pedro), and the NAS North Island for making their facilities available for the DEM/VALs of the LRDP system, and for coordinating and supporting the DEM/VALs. We would also like to acknowledge the input and support of the Defense Energy Supply Center (DESC) and Endress+Enhauser Coggins Systems. Ken Wilcox Associates, Inc., performed the third-party evaluation of the LRDP. The LRDP was initially developed by NFESC and Vista Research with funding from the Pollution Abatement Ashore Program, which is sponsored by the Environmental Protection, Safety and Occupational Heath Division (N45) of the Chief of Naval Operations, and from Vista Research. The work described in this report was funded through the Environmental Security Technology Certification Program (ESTCP) and is entitled, "Validation of the Low Range Differential Pressure (LRDP) Leak Detection System for Small Leaks in Bulk Fuel Tanks." A full list of contacts is included in Section 8 of this report.

The LRDP team would like to especially thank Dr. Jeffrey Marqusee and Dr. Robert Holst for their support.

Project Manager:	Leslie A. Karr, REM NFESC
Project Engineers:	William R. Major NFESC
	Dr. Vincent F. Hock CERL
Technical Director:	Dr. Joseph W. Maresca, Jr. Vista Research, Inc.
Design/Field Engineers:	James W. Starr, P.E. Vista Research, Inc.
	Gary A. Hayter Vista Research, Inc.

1.0 Executive Summary

The Naval Facilities Engineering Service Center (NFESC), Port Hueneme, California, and its industrial partners, Vista Research, Inc., and Vista Engineering Technologies, L.L.C., have demonstrated and validated (DEM/VAL) an innovative mass-based leak detection system for *bulk* fuel underground storage tanks (USTs). The *Low-Range Differential Pressure (LRDP)* system is a computer-controlled system that can reliably detect small leaks in bulk USTs ranging in size from 50,000 gal to 12,500,000 gal. As part of this project, it has been evaluated for performance by an independent third party in a 122.5-ft-diameter, 2,100,000-gal tank following EPA's standard test procedures. The LRDP meets monthly monitoring and annual precision (tightness) test regulatory compliance requirements using either a 10-h (overnight) or 24-h test.

This project was performed under the *Environmental Security Technology Certification Program (ESTCP).* The objective of the ESTCP is to demonstrate and validate innovative environmental technologies that are needed to address the environmental objectives of the Department of Defense (DoD), that are cost effective, and that will be ready for the development of commercial products and services at the completion of the DEM/VALs. All of the objectives of the project have been met, and the LRDP is ready for commercial use. Both (1) on-line, permanently installed monitoring systems and (2) tightness testing services using the LRDP can be obtained commercially through Vista Research, Inc.

The LRDP system achieves a very high level of performance against small leaks because of its high precision (0.0002 in.) and its accurate methods of compensating for the thermal expansion and contraction of the fuel, the instrumentation, and the tank. Because of its innovative design, the LRDP achieves this high level of precision and accuracy with an off-the-shelf, industrial-grade differential pressure sensor. Thus, the LRDP not only delivers high performance, but it is also rugged and field-worthy.

The LRDP system is fully automatic and is comprised of (1) an innovative in-tank level sensing unit, (2) an embedded remote test controller to collect and analyze the data from a test, and (3) a host computer to initiate, report, and archive the results of a test. A test can be initiated by an operator or can be automatically scheduled for a future date and time. The in-tank sensor can be installed through a standard 8-in.-daimeter opening without removing fuel from the tank. The electronics meet Class 1, Div. 1 standards. The LRDP system is compatible with the DoD Fuels Accounting System (FAS) and can be integrated with FAS to test the tanks in a fuel farm or a bulk storage facility.

The in-tank sensor is comprised of (1) a vertical reference tube that spans the full usable height of the tank, (2) a sealed, bottom-mounted container that houses all of the level-measurement sensors, and (3) a special bellows-mounting system that is used to attach the system to the top of the tank. A valve at the bottom of the reference tube allows fuel from the tank to enter or leave. When the tank is to be tested for leaks, the valve is closed, thus isolating the fuel in the tube from that in the tank. As the level of liquid in the tank fluctuates, the level of liquid in the closed reference tube mimics it—except when the change in level is due to a leak. High precision is achieved because

the dynamic range of the differential pressure sensor only needs to accommodate the differences in level between the tube and the tank and not the full height of the tank. The very small differences between the changes in level (pressure) in the tank and those in the tube are detected by a differential pressure sensor that is located in the sealed container at the bottom of the tube. Because the LRDP is housed at the bottom of the tank, where it is not subject to ambient air conditions, it avoids a common problem of other mass-based leak measurement systems—thermally induced drift of the pressure sensor. In addition, the special bellows-mounting system removes any thermally induced vertical movement of the tank, the manway, or the in-tank sensor.

The performance of the system was independently evaluated for a 10- and a 24-h test by Ken Wilcox Associates, Inc. (KWA), a nationally recognized third-party evaluator. The performance was determined experimentally and was reported in accordance with the guidelines set forth in "Alternative Test Procedures for Evaluating Leak Detection Methods: Evaluation of Bulk Field-Constructed Tanks," a standard test procedure for bulk underground tanks that is approved by the National Work Group on Leak Detection Evaluations (NWGLDE), an EPA-sponsored oversight group. A leak detection method cannot be used unless the evaluation has been approved by this group. The evaluation consisted of 12 blind tests conducted on a 122.5-ft-diameter, 2,100,000-gal bulk UST containing jet fuel and located at the Navy's Point Loma Fuel Terminal, San Diego, California. The tests were conducted over a wide range of temperature and induced leak conditions beginning on March 22, 2000 and ending on June 8, 2000.

The LRDP is currently listed by the NWGLDE and is approved for use in California based on a third-party evaluation previously conducted at NAS North Island on an 88-ft-diameter tank. The results of the current ESTCP evaluation, conducted on the 122.5-ft-diameter tank at Point Loma, a much larger tank than the one used in the North Island evaluation, have been submitted to the NWGLDE for review and update of the previous listings. The results of the KWA evaluation (which are presented in this report) indicate that a single 10-h test with the LRDP-10 can detect a leak of 1.14 gal/h with a probability of detection (P_D) of 95% and a probability of false alarm (P_{FA}) of 5% in a 122.5-ft diameter tank. The performance of the LRDP-10 scales with the product surface area of the tank and improves as the tank diameter decreases. The LRDP-10 can detect leaks as small as 0.2 gal/h in a single test in a 51-ft-diameter tank; by averaging four tests, a 0.2-gal/h leak can be detected in a 73-ft-diameter tank with the same probabilities of detection and false alarm. The performance improves with a 24-h test. The LRDP-24 can detect a leak of 0.69 gal/h with a P_D of 95% and a P_{FA} of 5% in a 122.5-ft diameter tank; when the 12 monthly tests are averaged together, the system has the capability for detecting leaks as small as 0.2-gal/h. The LRDP-24 can detect leaks as small as 0.2 gal/h with the same P_D and P_{FA} in a 66-ft-diameter tank with a single test and in a 93-ft-diameter tank by averaging four tests together. The LRDP-10 and the LRDP-24 are the only in-tank, on-line monitoring systems that can meet both Option 7 and Option 10 of the California regulatory guidelines for underground bulk storage tanks.

A DEM/VAL of the LRDP system configured to test 50,000-gal underground storage tanks was performed at Hunter Army Airfield. For these tests, the reference tube was shaped to match the cylindrical cross-section of the tank as a function of depth. While a third-party evaluation was not performed, it was clear from the results of the DEM/VAL tests that the LRDP could meet the 0.2-

gal/h monthly monitoring regulatory requirements with an 8-h test.

The LRDP has several significant cost advantages over other internal and external technologies. The cost advantages are realized because of the extremely high performance of the LRDP and the low probability of false alarm, the on-line monitoring capability of the LRDP when permanently installed in a tank, the capability of the system to conduct a short test (an overnight test), and the low recurring costs associated with testing. For each tank brought into compliance, the LRDP can realize cost savings over other mass-based methods in terms of installation and testing of $250,000 or a factor of 3 over a 10-year period. The cost savings realized by the LRDP over an in-tank tracer method can be well over $1,100,000 or a factor of 12 over a 10-year period. This can result in savings of up to several tens of millions of dollars for each DoD fuel storage facility. The savings of the LRDP compared to other mass-based systems would result in a payback of less than three years. This payback is less than one year when compared to an in-tank tracer method. The cost of a tracer method is expensive because of the high recurring cost of testing. The costs of other mass-based methods are high because of lower performance and the inability to meet both the monthly monitoring and annual precision regulatory requirements with an on-line system. In addition to the installation and operational cost savings, the LRDP has the potential to save DoD many hundred of millions of dollars in terms of clean-up and tank replacement cost avoidance.

2.0 Technology Description

The *Low Range Differential Pressure (LRDP)* system is an innovative technology that was developed for the reliable detection of small fuel leaks in the *bulk* underground storage tanks (USTs) that are owned or operated by the Department of Defense [1-2]. If a tank is leaking, the LRDP quantitatively measures the leak rate in gallons per hour, the quantity of regulatory interest. The LRDP system can be used to test tanks ranging in capacity from 50,000 gallons to 12.5 million gallons and will work for tanks with vertical and/or curved walls. The LRDP is a fully automatic, mass-based system, which is easy to install and use. It can be installed through a standard 8-in.-diameter opening without removing any fuel from the tank. The LRDP system can be permanently installed in a tank and used for on-line monitoring and precision (tightness) testing. It can also be used as a portable system for periodic testing of any tank in the fuel farm. The duration of a test can be either 10 or 24 h depending on the size of the tank and the performance required. A 10-h test can be used for most monitoring programs.

2.1 Technology Development and Application

A description of the LRDP system is given in Section 2.1.1 and four methods of implementing a leak detection test with the LRDP is described in Section 2.1.2.

2.1.1 Description

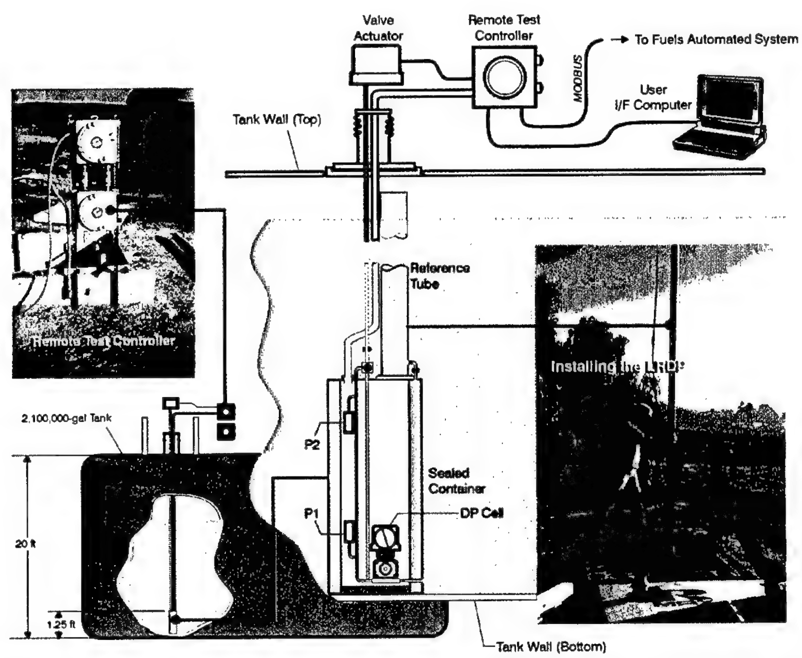

Figure 1. Low-Range Differential Pressure (LRDP) system for bulk USTs.

The pre-production prototype of the LRDP system, developed in this ESTCP project and shown in Figure 1, is comprised of (1) an in-tank level sensing unit, (2) a local embedded remote test controller to implement a test and to collect and analyze the data from a test, and (3) a host computer to initiate, display, report, and archive the results of a test. The level-measurement sensor is an industrial differential pressure (DP) sensor that is located in a sealed container at the bottom of the in-tank sensing unit. An illustration of the reference tube and the sealed container is also shown in Figure 1. Figure 2 shows the in-tank portion of the LRDP system, which can be installed through an 8-in.-diameter opening. A test is initiated by an operator using the host computer. The remote test controller, located in close proximity to the tank, automatically operates the LRDP system. A test report is generated upon completion of the test. The LRDP system is compatible with the DoD Fuels Accounting System (FAS) and can be integrated with FAS to test the tanks in a fuel farm or bulk storage terminal.

High performance is achieved with the LRDP system, because the novel design of the in-tank sensing unit results in (1) a very high precision for making level measurements with an off-the-shelf differential pressure sensor and (2) effective compensation of the thermally induced changes of the fuel, the sensors, the tank, and the mounting system. For bulk tanks, both high precision and effective compensation is required to meet regulatory guidelines.

The LRDP is designed to easily and accurately compensate for the major sources of noise that might occur during a leak detection test. Accurate compensation is obtained because the LRDP is specifically designed to compensate for each source of noise without the need for arrays of temperature sensors and delicate/expensive level sensors. As a consequence, all of the sensors are off-the-shelf, commercially available sensors that have a proven track record of performance. The reference tube, the bellows-mounting stand, and the bottom-mounted sensors are the key elements that lead to high performance. Other mass-based systems do not work as well because the sensors (1) are mounted at the top of the tank where they are subject to large diurnal swings in the ambient air temperature, (2) are very delicate and expensive to achieve the level of precision required to conduct a test, and (3) may require the use of nitrogen gas for operation.

Figure 2. Photograph of the in-tank portion of the LRDP system for a bulk UST with vertical walls.

The LRDP is the only in-tank system that has the performance to address both the monthly monitoring and annual precision test leak-detection regulatory requirements for bulk USTs [3, 4] without requiring the installation, operation and cost of a second system. Not only is the LRDP the only system that can cost effectively meet both requirements, it can meet these requirements with a very low probability of false alarm. *It is also the only system that can conduct an overnight test.*

The *in-tank level sensing unit* of the LRDP system that has been designed for bulk storage fuel tanks with vertical walls (that is, upright cylinders with flat bottoms), which is shown in Figures 1 and 2, is comprised of the following:

(1) a **reference tube** that extends from the top to the bottom of the tank

(2) a **valve**, located near the bottom of the tank, with which to open and close the tube

(3) a **sealed container** mounted at the bottom of the reference tube and containing all of the level-measurement sensors

(4) a **differential pressure sensor**, mounted in the sealed container, that measures the *difference* between the level of liquid in the tank and that in the reference tube

(5) two **pressure sensors**, mounted in the sealed container, that can be used to measure the level and specific gravity of the fuel in the tank

(6) a **temperature sensor**, mounted on the differential pressure cell in the sealed container, that can be used to compensate the differential pressure sensor or the pressure sensors for temperature, and/or to measure the temperature of the fuel at the bottom of the tank

(7) **electrical wires** (4-20 ma contained in a sealed conduit) that connect the bottom-mounted sensors to the data acquisition system outside the tank, and

(8) a special bellows-mechanical **mounting** system to eliminate thermal movement of the reference tube and transducer enclosure.

The fuel in the tank is allowed to enter or leave the reference tube through a valve located at the bottom of the tube. The valve is opened and closed electronically (a function that can also be done manually). Except for a test, the valve is left in the open position. This allows fuel from the tank to enter the reference tube until the level of liquid is the same in both. When the valve is open, i.e., when the level of liquid in the tube is identical to that in the tank, the precision and accuracy of the LRDP system can be checked. When the tank is to be tested, the valve is closed, isolating the fuel in the tube from the fuel in the rest of the tank. With the exception of a level change due to a leak, the level of the fuel in the reference tube mimics the level of the fuel in the tank. The DP sensor measures the difference in the levels of fuel between the reference tube and the tank. If the *rate of change* of the level in the tank (which can be expressed in terms of gallons per hour based on a height-to-volume conversion from the tank's strapping table) exceeds a pre-set detection threshold, the tank fails the test.

The *remote test controller*, shown in Figure 1, is located near each tank to be monitored and contains a microprocessor, a disk, a temperature sensor, and a stable resistor. The remote test controller can collect up to 8 channels of data, but more channels can be added, if required. Once a test is initiated from the Host Computer, the microprocessor collects, analyzes, outputs, and stores the data and the results. The analysis not only includes a computation of the measured volume rate, which is equal to the leak rate, if a leak is present, but also includes a comprehensive set of quantitative data quality indices (DQIs) that automatically assess the quality of the data before the data are used to complete a test. Up to 50 tests can be conducted and stored without downloading the data. The power supply and sensor electronics are also located in the controller unit. Because of the temperature sensitivity of the pressure sensors and the large swings that can occur in the ambient temperature during a test, a temperature sensor and a stable resistor are installed in the controller for compensation. Only one, either the stable resistor or the temperature sensor, is needed for compensation. However, both have been demonstrated as effective in this project.

The *host computer* is used to initiate a test, inspect the results in real-time, and report the results of a test. The graphical user interface is easy to use. A test is initiated by pressing a Start Test button. At the completion of the test, the results of the test are displayed.

2.1.2 Testing Methods

Table 1 summarizes four evaluated methods for conducting a test with the LRDP system that are designed to address the regulatory requirements summarized in Section 2.2. The name of the method contains the duration of the test in hours and the number of tests to be averaged. The LRDP-10 is implemented with a 10-h test, and the LRDP-24 is implemented with a 24-h test. The LRDP-10-n is a test that requires the averaging of "n" tests. All four methods, which were

submitted to the NWGLDE for updating the LRDP listing, can be used to test vertical-walled tanks with capacities greater than 50,000 gal and diameters less than 194 ft. The performance results for each method scales by the square root of the number of tests, n, averaged together, and linearly the product surface area (PSA). Finally, all four methods also can be used as a stand-alone monitoring or precision testing system.

Table 1. Summary of the Four Methods of the LRDP System for Bulk Tanks

Name of Test Method	Type of Test	Test Duration	Number of Tests Averaged Together
LRDP-24 Version "a"	Monitoring, Precision*	24 h	1 test
LRDP-24-n Version "a"	Precision*	24 h	$1 < n \leq 12$ tests
LRDP-10 Version "a"	Monitoring, Precision*	10 h	1 test
LRDP-10-n Version "a"	Precision*	10 h	$1 < n \leq 12$ tests

* Can be used to address the regulatory standards for a 0.20-gal precision test, when the monthly monitoring requirement is 2.0 gal/h or less.

Methods (1) and (2) are performed using a 24-h test, and methods (3) and (4) are performed using a 10-h test. For all four methods, a 2-h waiting period is required between the time of the last transfer and the beginning of a test. The only difference in the test protocol between the LRDP-10 and the LRDP-24 is the duration of the test. The 10-h test duration required by the LRDP-10 allows for monitoring tests to be conducted during an overnight period.

Methods (2) and (4) allow the results from up to 12 individual tests to be averaged together before determining whether or not the tank leaking. The number of tests to be averaged depends on the required performance. This type of method is normally used to meet the 0.2-gal/h precision (tightness) test requirement for the larger tanks owned by DoD. For each method in Table 1, one of four *detection thresholds* can be used to detect a specific target leak rate (TLR) with a $P_D = 95\%$, or to operate with a specific $P_{FA} \leq 5\%$. These thresholds were selected to insure that the LRDP system can be used as needed to satisfy specific regulatory TLRs, to minimize the P_{FA} (<< 5%) for successful operations, and to compare the performance of the LRDP directly to other methods of leak detection. The NWGLDE requires that each threshold be described by a different version number. As a consequence, there are 16 different ways to use the LRDP for testing tanks, and the evaluation results are described in four pairs of KWA evaluation reports [5-12].

2.2 Regulatory Requirements

The UST regulation, issued in 1988 by the EPA, *deferred* the requirements for testing bulk or field-erected USTs for leaks [3]. The main reason for the deferral of field-erected USTs was the lack of any technologies in 1988 that could reliably test these large tanks for leaks. Only the shop-constructed USTs, which are typically used at service stations and have capacities of 50,000 gal or less, were strongly regulated. In contrast, the large field-erected USTs, which have capacities between 100,000 to 12,500,000 gal, did not need to meet the rigorous leak-detection performance standards for monthly monitoring or annual tightness testing established for the smaller USTs typically found at retail petroleum service stations [3].

During the late 1990s, California, where the majority of all of DoD's bulk tanks are located, developed regulatory guidelines for testing bulk tanks [4]. Since the DoD owns almost all of the

bulk USTs in the United States, the California guidelines were mainly prepared for DoD compliance. The LRDP can be used to address three of the options without using any other method. The basic option for testing USTs, regardless of size, is to meet the 0.2-gal/h monthly requirement in the EPA UST regulation [3]. This option, included by California as Option 1, is overly stringent and does not allow for testing with a low enough P_{FA} for routine monitoring. Two of the ten testing options (Options 7, 10) developed by California were based on the input from discussions between state officials, NFESC and Vista Research. Both of these options required monthly monitoring and a periodic precision test. Option 7 requires that the tank be tested monthly with a system capable of detecting a leak between 0.3 and 1.0 gal/h and annually with a system capable of detecting a leak of 0.2 gal/h. Option 10 requires that the tank be tested monthly between 1.0 and 2.0 gal/h and semi-annually at 0.2 gal/h. The system must be evaluated for performance and have a $P_D = 95\%$ and a $P_{FA} \leq 5\%$. The other options are variances of the UST leak detection performance standards issued for the small USTs found at service stations and are not generally consistent with the design and operation of bulk USTs.

2.3 Previous Testing of the Technology

The LRDP was initially evaluated for performance at the NAS North Island on an 88-ft-diameter, 600,000-gal bulk UST. The performance is summarized in a technical report and in third-party evaluation reports prepared by Ken Wilcox Associates, Inc. [1,13]. The system is listed by the National Work Group on Leak Detection Evaluations [5]. An engineering prototype of the system was used in the evaluation. While functionally, it is identical to the LRDP system developed under the ESTCP program, it could not be operated as a stand-alone, fully automatic unit, could not fit into a standard 8-in.-diameter tank opening for installation, and could not be used to conduct an overnight test.

2.4 Advantages and Limitations of the Technology

The LRDP system has the following advantages:

- The LRDP can be directly inserted into a standard 8-in.-diameter opening in the tank.
- The LRDP can be used without removing fuel from the tank.
- The LRDP can be used to test USTs with both vertical and curved walls.
- The LRDP can be used to test a bulk UST in as little as 10 h, which is a significantly shorter test duration than other methods (24 to 72 h or longer).
- The output of a leak detection test is easy to interpret, because it is a direct measurement of the leak rate in gallons per hour, the quantity of regulatory and engineering interest.
- The LRDP system has been successfully demonstrated in a variety of DoD tanks.
- The LRDP system has been evaluated for performance and is listed with the National Work Group on Leak Detection Evaluations, a nationally recognized, regulatory group that allows the local and state regulatory agencies to select methods for their use.
- The LRDP system is the only mass-based system that can meet both the monthly monitoring and the semi-annual or annual precision test regulatory guidelines in California.
- The LRDP system is approved for use in California.

- Because the LRDP system is a mass-based system, it inherently compensates for the thermal expansion or contraction of the fuel in the tank during a test. Furthermore, accurate tests can be initiated without a long pre-test waiting period.
- The mounting system eliminates thermally induced movement of the reference tube during a test.
- Thermally induced drift of the differential pressure sensor is virtually eliminated, because it is mounted in a sealed container at the bottom of the tank.
- Because the differential pressure sensor used to measure level (volume) changes in the tank needs a dynamic range of only 1 in. (rather than the total height of the tank, like other mass-based systems), the LRDP has the precision (0.0002 in.) to detect very small leaks in large-diameter tanks.
- The system is self-calibrating, and the performance and functionality of the LRDP can easily be checked between leak detection tests.
- The sensors used to measure differential pressure, pressure, and temperature are robust and have been used commercially in the pipeline leak detection systems that Vista Research has been selling for many years.
- The recurring cost of using and maintaining the LRDP are significantly lower than tracer methods. The cost of compliance with other mass-measurement systems is significantly more expensive than the LRDP because these other mass-measurement systems cannot meet both the monthly monitoring and the annual precision testing regulatory. requirements.
- The LRDP system can be modified for testing aboveground storage tanks (ASTs).

The main limitation of the method is that all of the valves in the fuel facility that isolate the tank from its associated piping must seal completely; if these valves do not completely seal, the LRDP system detects this flow. This is not usually a problem for monitoring because the monitoring standards are high enough to accommodate small flows across the valve. For precision tests, however, the valves must seal completely. If the tank fails a test (either a monitoring or precision test), a detailed inspection of the tank and pipe valves is performed next assuming this is the reason for the failed test, and if necessary, valve blinds are installed to complete the test. In many instances, closing the valves tighter is all that is needed. The magnitude of this problem is not known for bulk tanks, but it is the same problem encountered and successfully addressed for routine monitoring of underground storage tanks at service stations.

3.0 Demonstration Design

3.1 Performance Objectives

The objective of this ESTCP project was to demonstrate and validate (DEM/VAL) a reliable, cost-effective leak-detection system for monthly monitoring and periodic precision testing of the *bulk* underground storage tanks (USTs) with vertical walls that are owned and operated by the DoD. This project was an expansion of the previous testing and regulatory approval obtained in California for the LRDP on an 88-ft-diameter bulk UST at NAS North Island [1,13]. The present tests were designed to demonstrate the system on larger tanks and to obtain regulatory approval for use of the system as an on-line monitoring system and with test duration shorter than 24 h (i.e., 10 h). The output of the project is an alpha-prototype of the LRDP leak detection system (1) that is ready for pre-production testing by industry and (2) that has been evaluated for performance by an independent third party following a *standard test procedure* developed by the EPA. An additional objective was to demonstrate that the LRDP system also can be used to test the smaller, 50,000-gal underground storage tanks with cylindrical walls.

The performance objectives of the DEM/VALs were established by the regulatory guidelines for detection of leaks in bulk USTs. The regulatory requirements for bulk USTs were deferred in the EPA regulation issued in 1988, because, at that time, there were no technologies available to test these large tanks [3]. Since there are no national regulatory compliance standards for bulk USTs, the California regulatory guidelines were adopted as the basis for the performance objectives of this project, because they are practical and the most stringent standards. These guidelines indicate that the leak detection system must be evaluated for performance by an independent third-party following a standard test procedure and submitted to the NWGLDE for review and approval [14]. Once the evaluation is approved, the method is included on a national list of leak detection methods that are ready for use by the states for meeting their leak detection compliance requirements. In order for a system to be used to meet the regulatory requirements for leak detection, it must have completed a third-party evaluation, be listed by the NWGLDE, meet the regulatory requirements of a state, and be approved by the state.

The results of this evaluation must be reported in terms of a probability of detection (P_D) of a target leak rate (TLR) and a probability of false alarm (P_{FA}). The regulatory requirements of each state are specified in terms of P_D, P_{FA}, and TLR. At a minimum, the P_D must be equal to or better than 95% and the P_{FA} must be less than or equal to 5%. The TLR for bulk USTs are typically 1, 2, or 3 gal/h for monthly monitoring and 0.2 gal/h for precision testing performed semi-annually or annually. For 50,000-gal USTs, a leak detection test must be conducted monthly and the TLR is 0.2 gal/h.

3.2 Selection of a Test Site/Facility

Since the leak detection system is not affected by soil conditions and site geology, and the evaluation procedure only requires a tank that is not leaking, two criteria were used in selecting a site. First, it was desired to perform the DEM/VAL in a tank with a large enough diameter to address all of the tanks used by DoD. The standard test procedure described in [14] allows the

results of the evaluation for mass-based systems to be used for any tank smaller than the tank used in the evaluation and any tank whose product surface area (PSA) is less 250% of the PSA of the evaluation tank. Second, it was desired that no inflow or outflow due to leaking valves or drainback from piping occur during the evaluation.

The Point Loma site was selected because of (1) the large size of the tanks storing fuel, (2) the valves isolating the tanks from the transfer piping were new double-block and bleed valves, (3) the integrity of the valve could be verified, and (4) the need and interest of the fuel farm for a cost-effective system for testing the tanks at the facility. The Hunter Army Airfield site was selected for the DEM/VAL, because this is typically the largest tank found at Army sites and there was on-site support and interest in fielding a DEM/VAL.

3.3 Site/Facility Characteristics

DEM/VALs of the technology were conducted at two sites. Brief descriptions of the Point Loma and Hunter DEM/VAL sites are provided below. For more details, see the ESTCP Demonstration Plan [15].

3.3.1 DEM/VAL 1: Point Loma Fuel Terminal (Third-Party Evaluation)

The Point Loma Fuel Terminal stores and supplies fuel to other facilities in the area (e.g., the NAS North Island). The facility has over 30 bulk USTs. The evaluation was conducted in Tank 175, one of the largest field-erected bulk USTs owned by DoD. Tank 175 is located in a hillside and stores 2,100,000 gal of JP-5 fuel. Fuel is pumped into the tank to fill it and the removal of fuel from the tank is accomplished by gravity. The tank is 122.5 ft in diameter and 23.5 ft in height. The tank is buried about 5 ft below the surface of the ground. The product surface area (PSA) of the tank is 11,786 ft^2. Level changes in this tank are converted to volume changes using a height-to-volume conversion (HVC) factor of 7,347 gal/in.

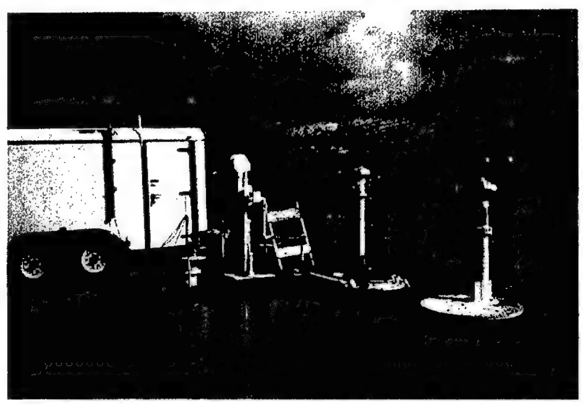

Figure 3. Tank 175 at the Point Loma Fuel Farm.

3.3.2 DEM/VAL 2: Hunter Army Airfield

There are 30 shop-fabricated 50,000-gal tanks at the Hunter Army Airfield (a sub-unit of Fort Stewart). Each of these tanks are nominally 10.5 ft in diameter, 80 ft in length, and are made of 3/8-inch thick welded steel. These tanks were installed in the 1952-53 time period. Until 1996, the tanks were used to store JP-5. In 1996, the facility converted to JP-8. Each 10-tank battery has a 6-inch diameter manifold connected supply pipeline and a 12-inch diameter discharge piping system running to the aircraft fueling area. An internal inspection, in 1997, of three selected tanks revealed the interior coating to be intact, with no signs of deterioration or significant corrosion. A DEM/VAL was conducted in Tank 45, one of the thirty 50,000-gal USTs.

3.4 Physical Set-up and Operation

The first DEM/VAL, a third-party evaluation, was performed in Tank 175, a bulk UST with vertical walls located at the Point Loma Fuel Terminal, San Diego, California. The second DEM/VAL was performed in Tank 45, a 50,000-gal UST with cylindrical walls, located at the Hunter Army Airfield, Savannah, Georgia. While a 50,000-gal UST is not considered a bulk UST, these large tanks are found at almost every bulk fueling facility and are used for storage of fuel before transfer into a hydrant pit or a loading rack. A formal third-party evaluation was not performed for this type of UST. Enough tests were performed to determine whether or not the technology had sufficient performance to meet EPA's 0.2-gal/h, monthly monitoring regulatory requirement for that type of tank [3]. If the LRDP is to be used for testing cylindrical USTs, a third-party evaluation will be required.

3.4.1 DEM/VAL 1: Point Loma Fuel Terminal (Third-Party Evaluation)

The LRDP was installed in the tank and checked out on 15-17 February 2000. Representatives from NFESC, KWA, Vista Research, and Vista Engineering were present. The LRDP was installed in an 8-in. opening (Figure 3). Figure 4 shows the top of the installed LRDP. A two-person team is needed to install the system. The total installation time requires less than 4 h to complete.

Figure 4. Photograph of the installation of the LRDP in the Point Loma tank.

The evaluation procedure requires that 12 tests be conducted with an induced leak rate that is not disclosed until after the evaluation is completed. The induced leaks were produced by pumping fuel out of the tank with a peristaltic pump. In three of the tests, no leaks were induced (0.0 gal/h). Leaks of approximately 0.4, 0.8, and 2.0 gal/h were randomly induced during the evaluation. This blind testing insures the integrity of the evaluation. The evaluation procedure requires that the evaluation be performed when the tank is approximately 90% of capacity and that six of the 12 tests be conducted following a fuel transfer. Before every other test, the fuel in the tank is lowered to 50% and fuel from another tank is then transferred into the tank to raise the level to 90%. Such transfers simulate operational conditions and produce a different temperature condition for each transfer. The temperature of the received fuel and the fuel in the tank is measured for each test and reported as part of the evaluation.

Testing during the evaluation was accomplished by KWA personnel following the LRDP testing procedures specified by NFESC and Vista Research. Leak simulations and fuel deliveries were defined and monitored by KWA. Leaks were induced by KWA with a peristaltic pump through the manway. The LRDP system was operated by KWA. The output of each test was automatically output from the system. The results from additional test durations were also output from a worksheet used by KWA using the same analysis procedure as used in the system. The

evaluation was interrupted, as required by fuel farm personnel, to support military and fuel operations. Delays of one or more days to a week or more sometimes occurred in executing the evaluation protocol.

For each test, the volume rate measured by the LRDP system was compared to the leak rate induced by KWA. Neither the nominal nor actual leak rate was made known to NFESC or Vista Research until many months after the evaluation had been completed and the final evaluation report was prepared. Leak rates were calculated from the total mass of fuel removed from the tank during the test and the density of the fuel that was measured with an analytical balance in a laboratory. The mass of the fuel removed from the tank was measured by pumping the fuel into a barrel hanging from a load cell. The uncertainty in the induced leak rates was less than 0.01 gal/h. During each test, KWA also verified the magnitude of the induced leak rate by measuring the pump rate with a graduated cylinder and a stop watch.

Fuel levels and fuel temperatures were electronically monitored by KWA throughout the evaluation using a level gauge and an RTD array. This allowed KWA to record and document the exact times and temperatures of the fuel deliveries. The temperature array consisted of RTDs located in the bottom 50% of the tank. A second LRDP, the one originally used at North Island, and KWA's level gauge and RTD array were installed in a 22-in.-diameter manway located about 10 ft away from the 8-in. opening (Figure 3). The peristaltic pump used to induce leaks in the tank was also located in this manway.

The evaluation was conducted over a three-month period beginning on March 22, 2000 and ending on June 8, 2000. The evaluation tests were conducted with the fuel at approximately 90% of capacity; the level was checked before each test to insure that it was below the top of the reference tube. The level of the fuel was lowered and raised approximately 10 ft to simulate a transfer of fuel; these transfers occurred immediately prior to the start of Tests 1, 3, 5, 7, 9, 11, and 12. Fuel transfers ranged from 467,271 gal (a level change of 63.6 in.) to over 852,255 gal (a level change of 116 in.). The temperature conditions ranged from –0.6° F to +1.4° F. The leaks induced by KWA, nominally 0, [-0.2, -0.3, -0.4], [-0.8, -1.0], and -2.0 gal/h, ranged from 0.0 gal/h to –1.93 gal/h.

Table 2. Summary of the Test Results and Induced Leak Rates for the LRDP Systems at Point Loma

Test No.	Test Start (m/dd/yy hhmm)	Induced Leak Rate (gal/h)	LRDP-10 VR* (gal/h)	LRDP-10 VR Error (gal/h)	LRDP-24 VR* (gal/h)	LRDP-24 VR Error (gal/h)
1	3/22/00 1539	-0.327	-0.179	-0.148	-0.327	0.000
2	3/23/00 1736	0.000	0.470	-0.470	0.232	-0.232
3	3/27/00 1519	-0.444	-1.142	0.698	-0.726	0.282
4	3/28/00 1728	-0.824	-0.908	0.0838	-1.072	0.248
5	4/05/00 1715	-1.040	-0.724	-0.316	-0.832	-0.208
6	4/06/00 1919	0.000	-0.059	0.059	0.081	-0.081
7	4/18/00 1614	-0.765	-1.014	0.249	-1.053	0.288
8	4/19/00 1740	-0.170	-0.566	0.395	-0.453	0.283
9	4/27/00 1308	-1.934	-2.194	0.260	-2.162	0.228
10	5/11/00 1500	-1.820	-1.797	-0.023	-1.834	0.014
11	5/12/00 1731	0.000	-0.238	0.238	-0.190	0.190
12	6/07/00 1557	-1.845	-1.786	-0.060	-1.997	0.152

* VR = Volume Rate

The measured volume rates measured by the LRDP for a 10-h test and a 24-h test are presented in Table 2. As part of the tests, data quality indices automatically checked to verify the quality of the data and to determine whether or not the tank was inadvertently used during the test (e.g., product transfers, or fuel or water sampling). The difference between the measured volume rate and the induced volume rate are also presented in Table 2. The volume rate errors are used to develop the performance of the LRDP system for each test duration.

3.4.2 DEM/VAL 2: Hunter Army Airfield

The DEM/VAL was conducted between 29 November and 2 December 1999 in Tank 45. The tank contained 38,100 gal (74% of capacity) for these tests. Figures 5 and 6 show the LRDP being installed in the tank through the standard 8-in.opening in the tank. The LRDP can be installed in less than four hours by a single person. The primary objective of the test was to demonstrate that the system could be used to test horizontal tanks for leaks. A special reference tube, whose cross-sectional area changed as a function of depth was used instead of the constant-diameter tube used for bulk USTs [16]. Three types of tests were conducted. The first was to demonstrate that the level of the fuel in the tank could be measured and used for inventory purposes. The second was to show that the system would respond if a known volume of product were to be removed or added to the tank. The third was to demonstrate that the LRDP had the capability to detect leaks as small as 0.2 gal/h.

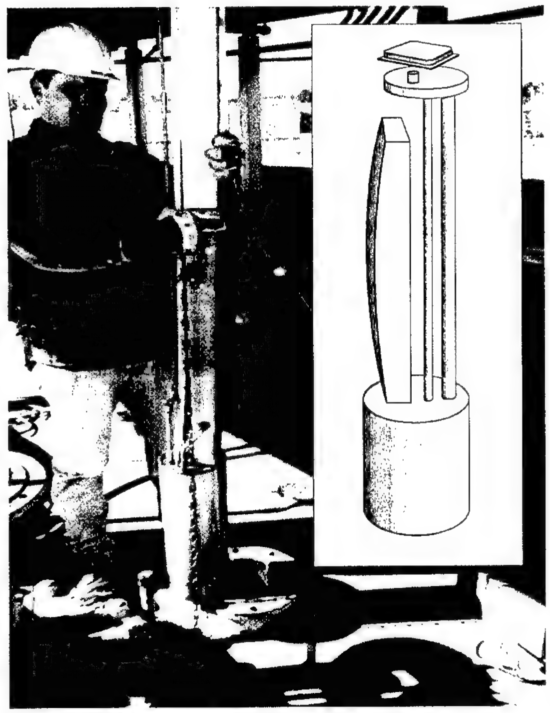

Figure 5. Installation of the LRDP in the 50,000-gal UST at the Hunter Army Airfield.

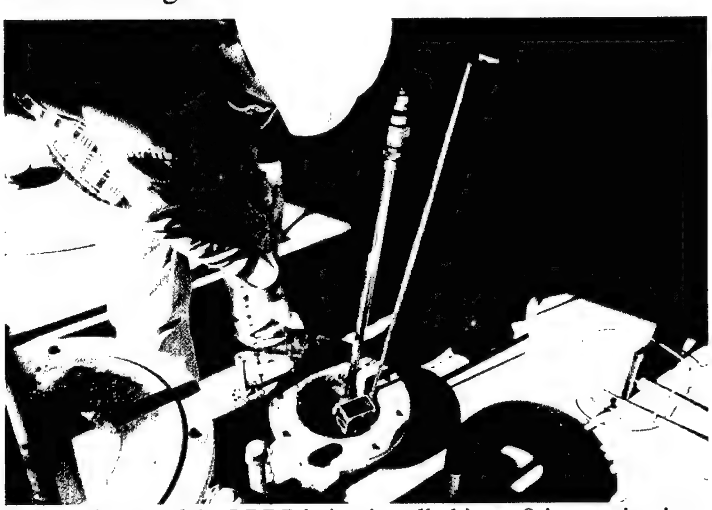

Figure 6. Top of the LRDP being installed in an 8-in.opening in a 50,000-gal UST at the Hunter Army Airfield.

A 24-h test was first conducted to determine whether or not the tank was leaking. Having determined that the tank was tight, a demonstration of the system was conducted for site personnel. The data collection period for the DEM/VAL was extended several days to acquire additional data to make an estimate of performance. After the demonstration, additional analyses were performed to estimate of performance of the LRDP for use in 50,000-gal USTs using test durations of 8 and 24 h.

In a vertical right regular cylinder, the free surface area of the fuel is constant regardless of level. In a tank with curved walls, however (e.g., a horizontal cylinder, or a vertical cylinder with a spherical top and bottom), the free surface area varies as a function of level. In this type of tank, a differential pressure sensor will not completely compensate for the thermal expansion or contraction of the fuel. To address this type of tank, the LRDP system incorporates a second design in which the cylindrical reference tube is replaced by a variable-shaped tube that mimics the cross-sectional changes in the tank's geometry. The same shaped reference tube can be used for all tanks with the same diameter, regardless of capacity. For best accuracy, the design of the tube should change as the diameter of the tank changes. For 50,000-gal tanks, two reference-tube designs would cover the range of tank diameters (generally 10.5 to 12.0 ft) found in commercial and DoD tanks.

To satisfy the 0.2-gal/h monthly monitoring regulatory standard, the LRDP would have to be able to detect a leak of 0.2 gal/h with a $P_D = 95\%$ and a $P_{FA} \leq 5\%$. This performance is achieved if the standard deviation of the error in the tests used in an evaluation is less than or equal to 0.06 gal/h. If only a single test was conducted, the error in this test would have to be less than 0.10 gal/h, as determined by a hypothesis test using a student's t distribution at a level of significance of 0.05.

A full-scale evaluation was not performed, because the scaled results of the bulk UST evaluation indicates that this level of performance would easily be achieved by the LRDP in a 50,000-gal UST. As a consequence, only a few tests were performed and a statistical comparison was made. A 24-h test was conducted on 19 November 1999, and 74 h of additional test data were obtained starting on 20 November 1999. The data from these two periods were grouped, and as shown in Table 3, the data were analyzed in 8 h and 24 h segments to make an estimate of performance. If the LRDP were to be used in these USTs for regulatory compliance, the LRDP would have to undergo another complete third-party evaluation.

Table 3. Summary of the Test Results for the LRDP Systems in a 50,000-gal UST at Hunter Army Airfield

Test No.	Test Start (mm/dd/yy hhmm)	Induced Leak Rate (gal/h)	8-h Test VR* (gal/h)	8-h Test VR Error (gal/h)	24-h VR* (gal/h)	24-h Test VR Error (gal/h)
1a	11/19/99 1155	0.000	-0.087	-0.087	0.014	0.014
1b	11/19/00 1939	0.000	0.027	0.027		
1c	11/20/99 0339	0.000	0.123	0.123		
2a	11/20/99 1604	0.000	-0.049	-0.049	0.010	0.010
2b	11/21/99 0004	0.000	0.051	0.051	0.010	0.010
2c	11/21/99 0804	0.000	0.042	0.042	-0.008	-0.008
2d	11/21/99 1604	0.000	-0.037	-0.037		
2e	11/22/99 0004	0.000	0.013	0.013		
2f	11/22/99 0804	0.000	0.014	0.014		
2g	11/22/99 1604	0.000	-0.080	-0.080		
2h	11/23/99 0004	0.000	0.010	0.010		
2i	11/23/99 0804	0.000	-0.025	-0.025		
2j	11/23/99 1604	0.000	0.066	0.066		

* VR = Volume Rate

3.5 Sampling/Monitoring Procedures

The third-party evaluation of the LRDP was conducted by Ken Wilcox Associates, Inc. (KWA) in accordance with the protocol described in the report "Alternative Test Procedures for Evaluating Leak Detection Methods: Evaluation of Bulk Field-Constructed Tanks" [14]. This test procedure follows EPA and ASTM standards for conducting and reporting the results of a third-party evaluation [14, 16]. This standard test procedure has been approved by the NWGLDE and is accepted by federal, state and local regulatory agencies as the means for demonstrating the performance of bulk tank leak detection systems.

4.0 Performance Assessment

The performance of the LRDP system was assessed for its suitability for both monthly monitoring and for annual or semi-annual precision (tightness) testing. The results of both DEM/VALs are summarized in this section. The performance of the LRDP for conducting both monthly monitoring and annual/semi-annual precision leak detection tests in bulk USTs that was determined during the third-party evaluation in the first DEM/VAL at Point Loma is described in Section 4.1. An estimate of the expected level of performance of the LRDP for conducting tests in 50,000-gal USTs that was determined during the second DEM/VAL at Hunter Army Airfield is described in Section 4.2. The performance of the LRDP system depends on the diameter of the tank, the duration of the test, and the number of tests averaged together.

4.1 Third-Party Evaluation Results for Bulk USTs

Ken Wilcox Associates, Inc., has prepared four evaluation reports (LRDP-24, LRDP-24-n, LRDP-10, LRDP-10-n) [5, 7, 9, 9, 11] summarizing the performance of the LRDP determined in the third-party evaluation. The performance estimates for additional implementations of the methods are summarized in a second set of reports [6, 8, 10, 12]. The results of this evaluation will replace the results for the LRDP-24 presently included in the eighth edition of the NWGLDE listing of leak detection systems with approved evaluations [13].

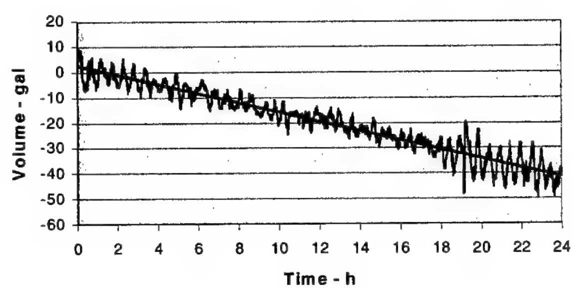

Figure 7. Level data obtained with the LRDP-24 system for Test 10.

4.1.1 Point Loma Evaluation Test Results

An example of the level data measured with the LRDP for a 24-h test is shown in Figure 7. The tests of the LRDP-10 were initiated at the same time as those of the LRDP-24, but only the first 10 h of the test were used in the analysis. The level data shown in Figure 7 are from Test 10, which was initiated at 1500 on 11 May 2000. The induced leak rate was 1.82 gal/h, and the leak rate measured by the LRDP system was 1.83 gal/h. The test was started at 1700 after a 2-h waiting period. The precision of the level measurements (i.e., the standard deviation of the data about a regression line fit to the data) is less than 0.0003 in. The linearity of the 24-h data in Figure 7 suggests that the volume rate estimated with these data should be about the same for both the 10-h and 24-h tests.

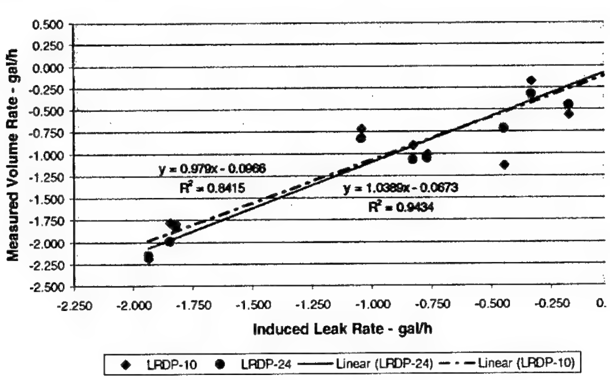

Figure 8. Least-squares lines fitted to the test results of the LRDP-10 and the LRDP-24.

The results of the leak detection tests for the LRDP-10 and the LRDP-24 that were presented in Table 2 are summarized graphically in Figure 8. Each test result is plotted against the leak induced for that test.

In Figure 8, the test results measured by the LRDP systems appear on the y-axis, while the KWA-induced leak rates appear on the x-axis. A least-squares line has been fitted to the results of the tests with each LRDP system. The slope of the line is nearly 1.0 (1.039 for the LRDP-10 and 0.979 for the LRDP-24); this indicates that the volume changes due to the induced leaks are additive with any other volume changes in the tank.

A summary of the statistics of the LRDP-10 and LRDP-24 determined in the evaluation is presented in Table 4. The performance in terms of P_D and P_{FA} are determined from the standard deviation assuming that the histogram of the noise and signal-plus noise are normally distributed.

Table 4. Mean and Standard Deviation of the Difference between the Measured Leak Rates (Test Results) and Induced Leak Rates for the LRDP-10 and LRDP-24

Type of LRDP System	Number of Tests	Mean Volume Rate (gal/h)	Standard Deviation (gal/h)
LRDP-10	12	0.080	0.318
LRDP-24	12	0.097	0.192

A statistical hypothesis test, as required by the evaluation protocol, was performed to determine if the mean was statistically different from zero. The results of a two-sided student-t test conducted at a level of significance of 0.05 indicated that the mean could not be distinguished from zero. This means that the system has no bias and that the mean computed in the evaluation does not have to be included in the threshold.

The performance of the LRDP-24 is better than the LRDP-10 because of the longer test duration. The difference in performance between the LRDP-10 and the LRDP-24 can be attributed to one or two of the evaluation tests. If the LRDP-10 measured the same result as the LRDP-24 for Tests 2 and 3, the mean and standard deviation of the LRDP-10 would be 0.066 gal/h and 0.226 gal/h, respectively, which means the performance of the LRDP-10 is similar to the LRDP-24 for most tests. Although its quoted performance is not nearly as good, in operation, it will give similar results for 80% of the tests conducted.

4.1.2 Performance Estimates for a Single Test (LRDP-10 and LRDP-24)

Estimates of the performance of the LRDP-10 and the LRDP-24, in terms of P_D and P_{FA}, were generated for the *evaluation tank* from the *standard deviation* of the test results given in Table 4. The minimum detectable leak rate (MDLR) is tabulated in Table 5 for the 122.5-ft-diameter evaluation tank and is the leak rate that can be detected with a $P_D = 95\%$ and a $P_{FA} = 5\%$. The

Table 5. Estimate of the Minimum Detectable Leak Rate (MDLR) for the LRDP-10 and the LRDP-24

Type of LRDP System	Threshold (gal/h)	Leak Rate (gal/h)	Probability of False Alarm (%)	Probability of Detection (%)
LRDP-10	0.570	1.14*	5.0%	95.0%
LRDP-24	0.345	0.69*	5.0%	95.0%

MDLR is determined from the 12 tests performed in the evaluation by multiplying the standard deviation by 3.592. The 3.592 value is twice the value obtained from a Student's t Distribution table for 11 degrees of freedom and a one-tailed test for a level of significance of 0.05, which results in a $P_{FA} = 5\%$ and a $P_D = 95\%$ (see reference [14] for more details). The MDLR for the LRDP-24 scales to a detectable leak rate of 0.36 gal/h in an 88-ft-diameter tank, the diameter of the bulk UST used in the first third-party evaluation at NAS North Island.

The formula for computing performance of the LRDP-10 and the LRDP-24 are summarized in the two tables in Appendix A for the various implementations of the method. For most implementations of the methods, the P_{FA} is usually less than 0.5%. Examples of the performance for different tanks diameters and target leaks rates are presented and discussed in the final report [18].

The performance of a leak detection system can be affected by the size and geometry of the tank. This relationship is not quantitatively understood for volumetric methods, but is predictable for mass-based systems like the LRDP system. For most mass-based technologies, performance is proportional to the product surface area of the fuel in the tank. The evaluation protocol specifies that the threshold for declaring a leak must be adjusted when testing tanks that are smaller or larger than the tank used in the evaluation. For a mass-based system, the threshold and the TLR are obtained from the ratio of the surface area of the tank being tested and the product surface area (PSA) of the tank used in the evaluation.

According to the evaluation protocol [14], the maximum tank size to which a mass-based method may be applied is determined by the product surface area of the tank and is limited to two and one-half times the surface area of the tank used in the evaluation. Since the surface area of the 122.5-ft diameter, 2,100,000-gal tank used in this evaluation is 11,786 ft^2, the LRDP-10 and the LRDP-24 can be used to test tanks with diameters up to 193.4 ft. The maximum tank capacity (in terms of volume of fuel in the tank) that can be tested with the LRDP systems is not constrained by the evaluation and will depend on the height of the tank.

4.1.3 Performance Estimates for More than One Test (LRDP-10-n and LRDP-24-n)

The performance of the LRDP-10 and the LRDP-24 (or any leak detection system) can be improved significantly by combining the results of two or more tests. Averaging two or more test results before applying the threshold will improve *both* the probability of detection and the probability of false alarm over that obtained for a single test. Performance improves as the number of tests averaged together increases. The performance will depend on the test duration and the number of tests, n, averaged together. For example, the performance of the LRDP-10-4 is a factor of 2.0 (square root of 4) times better than a single 10-h test with the LRDP-10; the LRDP-10-4 uses a test duration of 10 h and averages four 10-h tests together.

The performance of the LRDP-10-n and LRDP-24-n systems, where n is the number of independent tests averaged together, is obtained using the *standard deviation of the mean* test result, S_m, of the LRDP-10 and LRDP-24 systems. The standard deviation of the mean test result can be determined from the standard deviation of the single-test results, S, computed in the third-party evaluation. Once the standard deviation of the mean test result is known, the performance of the mean (average) test result (in terms of P_D and P_{FA}) can be computed using the same methods as for the single test results.

For independent tests, S_m of the LRDP-10 and LRDP-24 is obtained from S and the number of tests, n, averaged together. The standard deviation of the mean, S_m, is given by

$$S_m = S /(n)^{0.5} .$$

The average test result is important because it allows the same in-tank leak detection system to meet both the 0.3-1.0 or 1.0-2.0-gal/h monthly monitoring and the 0.2-gal/h annual leak testing requirements established by the state of California for bulk USTs. All of the LRDP systems can easily meet the monthly testing requirements with a very low probability of false alarm (<1%). With averaging, all of the bulk USTs owned or operated by the DoD can also meet the precision test requirements of 0.2 gal/h.

4.1.4 Summary of Performance Results for Different Size Bulk USTs

Tables 6-8 further summarize the results of the evaluation for different size tanks and different number of tests, n, averaged together. Table 6 gives the MDLR for n = 1, 4, 6, and 12 for three tank sizes.

Table 6. Example of the MDLR in gal/h (P_D = 95% and a P_{FA} = 5%) as a Function of Tank Diameter

Method	**PD-%**	**PFA-%**	**Target Leak Rate - gal/h for tank diameters of 122.5 ft**	**88 ft**	**60 ft**
LRDP-10	95%	5%	**1.14**	0.59	0.27
LRDP-10-4	95%	5%	0.57	0.29	0.14*
LRDP-10-6	95%	5%	0.46	0.24	0.11*
LRDP-10-12	95%	5%	0.33	0.17*	0.08*
LRDP-24	95%	5%	**0.69**	0.36	0.17*
LRDP-24-4	95%	5%	0.35	0.18*	0.09*
LRDP-24-6	95%	5%	0.28	0.15*	0.07*
LRDP-24-12	95%	5%	0.20	0.10*	0.05*

* Although the computed MDLR is less than 0.20 gal/h, the performance of the system must be reported and the system operated at 0.20 gal/h.

Table 7 gives the largest tanks in which the LRDP-10, LRDP-10-n, LRDP-24, and LRDP-24-n can meet the precision test TLR requirement of 0.20 gal/h with two different P_{FA}s. Table 8 gives the largest tank diameters in which the LRDP-10 and the LRDP-24 can meet the monthly monitoring standards of 0.3-1.0, 1.0-2.0, and 2.0-3.0 gal/h. Also, Table 7 shows that an annual precision test can be conducted in any tank with a diameter of less than 51 ft with a P_{FA} = 5%, which covers over 50% of the bulk USTs. The LRDP-10 can also be used to meet the precision requirement using a single test at a P_{FA} = 0.3% for all tanks with diameters less than 43 ft. Table 8 shows that the LRDP-10 can be used to address the 0.3-1.0-gal/h and the 1.0-2.0-gal/h monthly monitoring requirement for tanks with diameters up to 95 and 135 ft. respectively, with a very low P_{FA} (0.3%). This covers the

Table 7. Largest Diameter Tank in which a 0.20 gal/h Leak Rate Can Be Detected as a Function of the Number of Tests Averaged*

Method	**P_D**	**P_{FA}**	**TLR-gal/h**	**For Tank Diameters ≤** n=1	n=4	n=6	n=12
LRDP-10-n	95%	5.0%	0.20	51 ft	73 ft	80 ft	96 ft
LRDP-10-n	95%	0.3%	0.20	43 ft	60 ft	67 ft	79 ft
LRDP-24-n	95%	5.0%	0.20	66 ft	93 ft	103 ft	123 ft
LRDP-24-n	95%	0.5%	0.20	56 ft	80 ft	88 ft	105 ft

* P_D = 95% and a $P_{FA} \leq$ 5% for the LRDP-10, LRDP-10-n, LRDP-24, and LRDP-24-n as a Function of Tank Diameter and Averaging (n = 1, 4, 6, 12)

full range of bulk USTs owned or operated by the DoD.

As shown in Table 8, with the LRDP-24, the 0.3 – 1.0-gal/h monthly monitoring requirements can be addressed for all but a few of the largest bulk USTs owned by DoD. The advantage of using the 0.3 – 1.0-gal/h criterion is that only a single precision test at 0.2 gal/h is required each year. In addition, Table 8 shows that the LRDP-24 can be used to address the 0.3 – 1.0-gal/h and the 1.0 – 2.0-gal/h monthly monitoring requirement for tanks with diameters up to 126 and 178 ft. respectively, with a low P_{FA} (0.5%). This covers the full range of bulk USTs owned or operated by the DoD. Also, Table 7 shows that an annual precision test can be conducted with the LRDP-24 in any tank with a diameter of 66 ft with a P_{FA} = 5%, which covers over 50% of the bulk USTs. If a precision test is conducted with the LRDP-24, then all of the 88-ft-diameter tanks at the North Island fuel farm can be tested in compliance with California regulations by conducting a precision test four times a year.

Table 8. Largest Diameter Tank in which Various Leaks Can Be Detected as a Function of Target Leak Rate (TLR)*

Method	P_D	P_{FA}	Tank Diameters for TLRs in gal/h			
		for TLR in gal/h =	0.30	1.0	2.0	3.0
LRDP-10	95%	0.3%	52 ft	95 ft	135 ft	165 ft
		for TLR in gal/h of	0.30	1.0	2.0	3.0
LRDP-24	95%	0.5%	69 ft	126 ft	178 ft	218 ft

* P_D = 95% and a $P_{FA} \leq$ 5% for the LRDP-10 and the LRDP-24

4.1.5 How to Use the LRDP System

The LRDP system gives the tank owner or operator great flexibility in developing a testing strategy for meeting the monthly monitoring and the precision test regulatory requirements. The overnight testing capability of the LRDP-10, the high performance of the LRDP-24, and the capability for averaging tests together allow a testing strategy to be developed that includes both methods. Tables 7 and 8 suggest how the system may be used. The detailed calculations can be made using the formula in Appendix A.

The guiding principle that should be used when developing a testing strategy is to minimize the probability of a false alarm. Any P_{FA} that is less than 1% will suffice, but it is highly desirable to have the P_{FA} < 0.1%. Experience shows that the P_{FA} computed using a normal distribution, as required by the EPA standard test procedures, is reasonably accurate for estimating the P_{FA} at 5% but results in a lower than observed P_{FA} for P_{FA}s < 1%.

The performance of the 10-h test is sufficiently good that almost all of the monthly monitoring tests, regardless of tank size, can be conducted using a 10-h test. For tanks with diameters less than 51 ft, the 10-h test could also meet the 0.2-gal/h precision testing criterion established by the State of California. By averaging 4 tests together, tanks as large as 73 ft in diameter could be tested. When the LRDP was used for monitoring at 1.0, 2.0 or 3.0 gal/h, both tests had a P_{FA} < 0.3% for all tanks owned or operated by DoD.

The LRDP can be used to address all three of the California regulatory options for testing bulk USTs. These three testing options are described in Section 2.2. As indicated by Table 7 for the smaller bulk USTs, the LRDP-10 or LRDP-24 meet the 0.2-gal/h monthly monitoring requirement

outright. However, it is probably more cost efficient and less disruptive to operations for 12 monthly tests to be performed using the 0.3 – 1.0-gal/h monthly monitoring option and one annual test at 0.2 gal/h than 12 monthly tests at 0.2 gal/h. This latter approach minimizes the potential for false alarms and provides excellent environmental protection well within the regulatory standards. If this latter approach is used, small valve weeps would not interfere with the monthly monitoring testing. For the largest DoD bulk USTs, the only available strategy may be to use the LRDP-24 to test at 0.2 gal/h.

The exact option to select for the tank owner/operator to use will depend on the size of bulk USTs at the facility. The provider of the LRDP can help the tank owner/operator design a testing program that is best for the facility. The first step in the design process is to determine which LRDP system can be used for monitoring and which LRDP system can be used for precision testing with the fewest tests to be averaged and the lowest P_{FA} that can be used. Once this is completed, a test protocol which uses the minimum number of testing combinations (methods and versions) should be selected. The added time required to design the testing program in the beginning will have great benefits once it is implemented.

4.2 Results of the DEM/VAL of the LRDP in a 50,000-gal UST

The results of the DEM/VAL conducted on a 50,000-gal UST at Hunter Army Airfield (Table 3) showed that the LRDP has more than sufficient performance to test tanks with cylindrical walls and meet the 0.2-gal/h regulatory criteria for monthly monitoring. This was accomplished by conducting a few tests and showing the results were not statistically different than the evaluation results for the larger bulk UST at Point Loma. The evaluation results indicated that the LRDP would be able to detect a TLR = 0.2 gal/h with a P_D = 95% and a $P_{FA} \leq 5\%$. A formal third-party evaluation was not performed for this type of UST. If the LRDP is to be used for testing cylindrical USTs, a third-party evaluation will be required.

The LRDP was used as a portable system for these tests. The system was unpacked, pressure tested, and installed in Tank 45 in less than a day. Though there were two people on-site at all times, for this size of system (10.5-ft-diameter), a single person could easily install and remove the system. Upon installation, it was demonstrated that the LRDP could measure the level of the fuel in the tank to within 1/8 in., the regulatory requirement for inventory measurements.

Table 9. Estimate of the MDLR for the LRDP made for an 8-h and a 24-h test duration in a 50,000-gal UST.

Performance Parameters	**8 h**	**24 h**
November 19-20, 1999 Data		
Test Duration – h		
Mean – gal/h	0.000	0.006
Standard Deviation – gal/h	0.047	0.010
Count	13	4
Threshold – gal/h	0.084	0.023
MDLR –gal/h	0.168	0.047
Precision Test MDLR – gal/h	0.200	0.200
Precision Test Threshold –gal/h	0.116	0.177
Precision Test P_{FA}	1.5%	< 0.001%

A 24-h test was then performed with the LRDP system to determine whether or not the tank was leaking. The test result was a PASS. The LRDP-24 measured a volume rate of 0.014 gal/h, which

is significantly less than a threshold of 0.16 gal/h that would be used to declare a leak in this tank. Based on this test it was clear that a shorter test than 24 hours could be used and still meet the 0.2 gal/h monthly monitoring criteria. A 74-h data set was obtained and the data were evaluated for test durations of 8 h and 24 h. The results summarized in Table 9 show that a leak rate criterion of 0.2-gal/h is achievable in the 50,000-gal tanks with an 8-h test duration.

5.0 Cost Assessment

This section summarizes the cost and cost savings achievable with the LRDP for testing bulk USTs. This section also compares the cost of the LRDP to other in-tank mass-based systems and external tracer-based systems. The cost advantages of the LRDP are realized because of the extremely high performance of the LRDP, the on-line monitoring capability of the LRDP when permanently installed in a tank, the capability of the system to conduct a short test (an overnight test), and the low recurring costs associated with routine testing to address regulatory requirements.

5.1 Cost Reporting

Two DEM/VALs of the technology were conducted. The cost of these DEM/VALs are summarized in Table 10. The first DEM/VAL was to install an LRDP system in a 2,100,000-gal bulk UST (Tank 175) at the Point Loma Fuel Terminal, San Diego, California, and to conduct a third-party evaluation to determine performance. The second DEM/VAL was to conduct a series of tests with the LRDP in a 50,000-gal shop-fabricated UST (Tank 45) at Hunter Army Airfield, Savannah, Georgia. With the exception of the reference tube, the same LRDP system was used for both DEM/VALs. The DEM/VAL costs include an initial site visit, installation, checkout, and removal of the equipment, and conduct of the DEM/VAL (data collection, analysis, and briefing of the results). The DEM/VAL at Point Loma required the collection of data over a 2-month period to check out the system and over a 3-month period to conduct the third-party evaluation. The DEM/VAL at Hunter was only a demonstration of the technology and was completed in less than two weeks.

Table 10. Summary of the Costs of the Two DEM/VALs of the LRDP System

DEM/VAL	Cost of the DEM/VAL	Cost of the Third-Party Evaluation	Total
Point Loma Fuel Facility	$75,000	$45,000	$120,000
Hunter Army Airfield	$25,000	N/A	$25,000
Total	**$100,000**	**$45,000**	**$145,000**

5.2 Cost Analysis

The total life-cycle cost of leak detection includes the following items:

- ***Cost of Regulatory Compliance:*** Purchase, installation, and operation of a leak detection system (direct and recurring costs)
- ***Cost Avoidance***
  - ***Fines and Shutdown of Operations:*** Costs associated with fines for not being in compliance and the cost impact on operations and operational readiness. (direct cost)
  - ***Tank Replacement Cost Avoidance:*** Pre-mature replacement of tanks (direct cost)
  - ***Remediation/Cleanup Cost Avoidance:*** Clean-up costs due to lack of testing or testing mistakes (direct cost)

- ***Commercialization and Technology Transfer Cost:*** Commercialization of the pre-production system (direct cost)

It is possible to make an estimate of all of these costs, because the performance of the leak detection system is known through the third-party evaluation. The P_D and P_{FA} allow estimates of the cost of testing mistakes, remediation, and tank replacement to be made. The *cost of regulatory compliance* is described below; the costs associated with *cost avoidance* and *commercialization and technology transfer* are described in Section 6.2.

Regulatory compliance will include the costs associated with the purchase, installation, and use of a leak detection system. It is estimated that the DoD owns or operates approximately 300 bulk UST with capacities greater than 100,000 gal. The life-cycle cost of a leak detection technology is comprised of the elements in Table 11. The Startup costs are fixed costs associated with the purchase, installation, and operator training. The Operational and Maintenance costs are also fixed and are small for the LRDP. The recurring costs associated with Compliance Testing and Test Mistakes are very small. Once the LRDP is permanently installed, a test can be initiated by pressing a start button.

In general, it is not the direct costs that control the price of a leak detection system. Rather, the recurring costs of monthly monitoring and annual precision testing tend to control. For poor performing systems with a higher than desired P_{FA}, the cost of testing increases, because

- additional tests with the same system or another system will have to be conducted to distinguish false alarms from leaks,
- site investigation may be required in terms of monitoring wells or uncovering of buried tanks to determine whether or not the tank is actually leaking,
- such false declarations may have to be reported to regulatory authorities with all the ramifications of such a report, and
- the activities required to determine whether or not a failed test is a false alarm will shutdown facility operations until the false alarm can be resolved.

If the P_{FA} is unacceptably too high, operational experience indicates that fuel farm personnel often do not operate or trust the equipment, and thus, leaks may go undetected. This can be very costly because of the remediation costs associated with undetected leaks.

Table 11 summarizes the costs associated with regulatory compliance with the LRDP. A Parts List for the LRDP is presented in Section 6.4 of the final report [18]. The purchase price of an LRDP assumed for this estimate is based on the purchase of 10 to 20 in-tank sensor units. Table 11 presents the cost model in terms of a percentage (%) of the equipment purchase price. The costs of false alarms and missed detections are based on an assumed price for additional testing ($500) and an average remediation cost ($750,000 per incident). The average remediation cost is based on 890 remediation jobs performed by the Navy. These two costs are indicated in the table heading. It is assumed that the P_{FA} is less than 0.1%, and that the probability of a missed detection is $P_{MD} = 1 - P_D = 5\%$ for a target leak rate of 0.2 gal/h. It is further assumed for this computation that 10% of all of the bulk USTs owned by the military are leaking. Because small leaks can be detected with the LRDP, the large average cost of remediation can be greatly

reduced; for this calculation, it is assumed that the cost of remediation is 25% of the average cost.

An important cost is the cost of shutdown associated with testing and testing mistakes (false alarm investigations). Since the military is not selling fuel commercially, any short-term or permanent shutdown of fueling operations is difficult to quantify in terms of dollars. However, it is unacceptable to shutdown military operations, or to seriously impact operational readiness. An estimate of $40,000 for a False Alarm mitigation was used in Table 11, resulting in a $40 per tank cost at a P_{FA} of 0.1%. The total cost per tank is $69,000. A cost comparison of the LRDP and tracer and other mass-measurement systems is given in Section 5.3.

Table 11. Compliance Monitoring Technology Costs for the LRDP on a Per Tank Basis

Direct Environmental Costs				**Recurring or Variable Environmental Costs**			
Startup		**Operation & Maintenance**		**Compliance Testing**		**Testing Mistakes**	
Equipment Cost	$40,000	Equipment Cost	$40,000	Equipment Cost	$40,000	FA Mitigation Remediation	$40,000 $750,000
Activity	**%**	**Activity**	**%**	**Activity**	**%**	**Activity**	**%**
Facility preparation, mobilization	$4,000 (10%)	Labor to operate equipment	$4000 (10%)	Monthly monitoring	$400 (1%)	False alarms (P_{FA} =< 0.1%)	$40 (0.1%)
Equipment Design	$4,000 (10%)	Utilities	$800 (2%)	Annual precision testing	$400 (1%)	Missed detections*	$938 (0.125%)
Equipment purchase	$40,000 (100%)	Consumable and supplies	$400 (1%)	Facility shutdown costs for testing	$1,200 (3%)		
Installation	$8,000 (20%)	Equipment maintenance	$2,000 (5%)				
Training of Operators	$2,000 (5%)	Training of operators	$800 (2%)				
Total	**$58,000 (145%)**	**Total**	**$8,000 (20%)**	**Total**	**$2,000 (5%)**	**Total**	**$978**

* It is assumed that the P_D = 95% against a TLR = 0.2 gal/h and the number of leaking tanks is 10% of the 300 bulk USTs owned by the DoD. It is further assumed that all of the tanks are tested at a TLR of 0.2 gal/h, and as a consequence of testing at such a small leak rate, the remediation average remediation costs are assumed to be 25% of the average remediation costs.

5.3 Cost Comparison

The LRDP has several significant cost advantages over other technologies. An estimate of the cost savings realized by the LRDP over two other methodologies is shown in Tables 12 - 14. Method 1 represents a tracer method with a high recurring cost of Compliance Testing. Method

1 assumes that a tracer must be added to the tank; no cost estimate is provided for tracer methods that use constituents in the fuel as tracers, because their performance has been found to be unacceptable. Method 2 is an in-tank mass-based method with the capability to only meet the monthly monitoring requirements. No other permanently installed in-tank, mass-based system besides the LRDP has the capability to meet the annual 0.2-gal/h performance standard. No specific commercial methods are identified by brand name here, but the cost savings achieved with the LRDP over a tracer method is due to the small recurring cost of testing with the LRDP and over the other in-tank methods is due to the fact that the LRDP can be used to meet the annual precision test as well as the monthly monitoring tests. The best way to interpret the tables is to examine the relative cost savings between the LRDP and the other methods. The calculation uses the fixed Start-up costs and the recurring Compliance Testing costs from Table 11 for the LRDP.

The cost comparison calculation is done as follows. First, it was assumed that the Startup and O&M costs are the same for all methods. Established price lists for bulk leak detection systems are not generally available, because most product sales or testing jobs are performed under a unique contract bid. This computation assumes $75,000, which is higher than anticipated for the LRDP and is probably lower than anticipated for Methods 1 and 2. This estimate includes the one-time purchase of the equipment for $40,000 (same as for the LRDP), as well as the operation and maintenance cost, the cost of testing and testing mistakes. The one-time purchase of equipment can be as high as $75,000 for mass-based systems. Second, the real cost savings of the testing tends to be controlled by the recurring cost of testing or the cost of additional testing because of lack of capability of the method to satisfy both the monthly monitoring and the annual precision test. The estimate assumes that 12 monthly tests and one annual precision at 0.2 gal/h are conducted each year. Third, there are significant cost savings associated with cost avoidance and remediation/cleanup because accurate and reliable leak detection is being performed. It is safe to say that the DoD would realize significant cost savings (many hundreds of millions of dollar) if any leak detection system was installed and used. If a reliable and accurate leak detection system is used, these savings can be a factor of 2 to 5 greater. These latter cost savings are not included in this calculation. Fourth, this cost comparison does not include the costs of Testing Mistakes. The number of tests to be conducted each year will be increased (1) if the leak detection system is susceptible to false alarms, or (2) if tests need to be repeated, because they are too long and must be prematurely terminated or because they interfere with operations.

Table 12 summarizes the cost of the initial purchase and installation of the leak detection system, the cost of performing 12 monthly tests, and the cost of performing an annual precision test. It is assumed that Methods 1 and 2 have the capability for performing the monthly monitoring test, but only Method 1 also has the capability for performing the annual test. It is assumed that Method 2 must use Method 1 to perform the annual precision test. It is also assumed that the recurring cost of testing is high for Method 1 as compared to the LRDP and that the recurring cost of testing is the same as the LRDP for Method 2. Table 13 summarizes the total cost of meeting the regulatory requirements for a single bulk UST for all three methods. Clearly, the recurring cost of Method 1 dominates the cost of testing. Table 14 summarizes the cost for a fuel farm containing 15 bulk USTs. The total cost savings throughout DoD would be a factor of about 20 higher.

The ratio of the cost of each method relative to the LRDP are given in the tables. The savings of the LRDP compared to Method 1 would result in a payback period of less than one year, and the savings compared to Method 2 would result in a payback period of approximately three years, even without including the savings due to fewer tank replacements and lower remediation costs. *When Methods 1 and 2 are compared to the LRDP, the cost of the other methods is a factor of 3 to 12 higher than the LRDP.*

Table 12. Comparison of the Cost of Testing in Dollars ($) with Monthly Monitoring and an Annual Precision Test for Each Bulk UST for the First Year

	Purchase of System	Monthly Monitoring			Precision Test	Total
	Initial Purchase for One UST	Conduct of a Single Test	Cost of 12 Monthly Tests	Cost of Monthly Monitoring for First Year	Annual Cost of Precision Test	Cost of Compliance for Year 1
Method 1	75,000	10,000	120,000	195,000		195,000
Method 2	75,000	240	2,880	77,880	25,000	102,880
LRDP	75,000	240	2,880	77,880		77,880
Method 1/LRDP						2.5
Method 2/LRDP						1.3

Table 13. Comparison of the Cost of Testing in Dollars ($) with Monthly Monitoring and an Annual Precision Test for Each Bulk UST Over 1, 3, 5 and 10 Years

Testing Method	Total Cost of Compliance for			
	First Year	Three Years	Five Years	Ten Years
Method 1	195,000	435,000	675,000	1,275,000
Method 2	102,880	158,640	214,400	353,800
LRDP	77,880	83,640	89,400	103,800
Method 1/LRDP	2.5	5.2	7.6	12.3
Method 2/LRDP	1.3	1.9	2.4	3.4

Table 14. Comparison of the Cost of Testing in Dollars ($) with Monthly Monitoring and an Annual Precision Test for 15 Bulk USTs Over 1, 3, 5 and 10 Years

Testing Method	Total Cost of Compliance for			
	First Year	Three Years	Five Years	Ten Years
Method 1	2,925,000	6,525,000	10,125,000	19,125,000
Method 2	1,543,200	2,379,600	3,216,000	5,307,000
LRDP	1,168,200	1,254,600	1,341,000	1,557,000
Method 1/LRDP	2.5	5.2	7.6	12.3
Method 2/LRDP	1.3	1.9	2.4	3.4

6. Technology Implementation

6.1 Cost Observations

The DoD owns and/or operates almost all of the bulk USTs in the United States. While the leak detection requirements for bulk USTs (i.e., field erected USTs) were deferred in EPA's UST regulation issued on 22 September 1988, many of the states have or are in the process of requiring testing of such tanks. California has developed a set of regulatory guidelines for testing bulk USTs. Other states, like New York, Michigan, Maine, and Florida also require bulk USTs to be tested. The requirement for testing may cost many tens to hundreds of millions of dollars, depending on the testing approach used. The LRDP can realize significant cost savings for the DoD because of its high performance (low P_{FA}) for detection of small leaks, low recurring cost for routine testing, and the ability to address both the monthly monitoring and the annual precision testing with the same system. The recurring cost of the LRDP is a factor of 3 to 12 times less than competing technologies.

The cost of compliance and a comparison of the costs between the LRDP and other methods were described in Section 5. A discussion of the additional cost savings that can be realized due to cost avoidance and commercialization/technology transfer is presented in Sections 6.1.1 and 6.1.2.

6.1.1 Cost Avoidance

The magnitude of the cost savings that can be realized by minimizing testing mistakes, managing tank replacement efforts and minimizing remediation/clean-up efforts through early detection of a release is a direct function of the use and performance of the leak detection system. If equipment is used frequently and the performance is high (i.e., the probabilities of false alarm and missed detection are low), then the need to routinely replace tanks can be minimized. They can continue to be used with confidence that they are not leaking, and if a leak develops, that it will be quickly detected. This reduces the volume of fuel released into the ground and the scope and cost of the cleanup. The high performance of the LRDP means that the number of false alarms and missed detections will be much smaller than other technologies. Furthermore, the high performance of the LRDP allows the probability of false alarm of the system to be set to a very low level without sacrificing the detection of small leaks. The other mass-based systems and some tracer-based approaches do not have the performance to operate with a low probability of false alarm. In addition, other mass-based methods must operate at a higher target leak rate. The total cost savings that can be realized by implementing a reliable leak detection program can be $500 million to $1 billion dollars. These cost savings are described below.

Fines and Shutdown of Operations. The cost of testing more than offsets the cost of the fines that may be levied if the tanks are not tested within the specified regulatory guidelines and are out of compliance. Fines may be $25,000 per day per facility, or more. Ultimately, if the bulk USTs are not in compliance, fuel operations can be shut down. Since the military is not selling fuel, any permanent or short-term shutdown of fueling operations is difficult to quantify in terms of dollars. However, it is unacceptable to shutdown military operations, or to seriously impact operational readiness. Because the LRDP has the performance to perform both the monthly

monitoring and the annual precision test, it is the most cost effective way to be in compliance. Because in many instances, an LRDP test can be performed in 10 h rather than the 48 or 72 h required by other methods, the impact on shutdown is significant.

Tank Replacement Cost Avoidance. Most bulk USTs are expensive to replace; the costs per tank can be tens of millions of dollars. Replacement costs can be minimized, avoided, or delayed by using accurate and reliable leak detection. There are two types of tank replacement programs. First, the DoD has considered simply replacing all of the bulk USTs with bulk ASTs. The costs associated with such an approach would be well over $400,000,000. Second, the DoD will need to replace or retrofit tanks as required for safe storage. The use of accurate and reliable leak detection can justifiably and safely avoid premature replacement of tanks. The cost savings associated with the use of leak detection is very large. For example, the U. S. Army has estimated that it would cost over $10,000,000 just to replace the 50,000-gal USTs at the Hunter Army Airfield (without testing equipment or testing services) as opposed to $3,100,000 for implementation of a testing program with the LRDP over a 10-year period. For our calculations, we assumed that the cost of replacement is $5 per gallon of stored fuel.

Remediation/Cleanup Cost Avoidance. The cost of remediation and cleanup are by far the largest costs associated with leaking tanks and clean-up cost avoidance can be the most significant cost savings realized with the purchase, installation and use of reliable leak detection. It is difficult to estimate the portion of the costs associated with clean-up that can be avoided, but it is significant. The Navy has 659 future LUFT sites to clean up and has estimated that the total cost will be $890,000,000. Early detection of leaks can significantly reduce the total cost of cleanup because the concentration and areal extent of the plume is smaller than it would be if the leak was not detected early.

6.1.2 Commercialization and Technology Transfer

The costs associated with technology transfer and commercialization have been minimized for the LRDP, because the third-party evaluation has already been completed and submitted to the NWGLDE for review and approval, and one company, Vista Research, has already commercialized the pre-production system. The former is a significant barrier (both in cost and time) for entry into the marketplace, and the later can take many years for industry to commit the resources needed for commercialization.

6.2 Performance Observations

All of the performance objectives of this program were met. The LRDP was successfully demonstrated in two DEM/VALs. The evaluated performance obtained in the third-party evaluation during the first DEM/VAL at Point Loma is sufficient to address all of the regulatory requirements for DoD's bulk USTs. The results of the DEM/VAL on the 50,000-gal USTs at the Hunter Army Airfield indicates that the system has the performance to meet EPA's 0.2-gal/h monthly monitoring requirements for testing these tanks.

6.3 Scale-up

The DEM/VALs were all conducted on full-scale, operational underground storage tanks. The

DEM/VALs were conducted on one of the largest bulk USTs and the largest cylindrical USTs tanks found in the DoD. The performance of the LRDP in other tanks scales with tank diameter (or equivalently, the product surface area of the fuel in the tank). As the tank diameter decreases, the performance improves and smaller leak rates can be detected. The LRDP can be used to test tanks with capacities as small as 50,000 gal and as large as 12,500,000 gals, which includes the largest tanks found in the United States.

6.4 Other Significant Observations

All tank operations must cease during a test; no fuel transfers in or out of the tank are allowed. This temporary shutdown of the tank is minimized by the LRDP in comparison to other in-tank leak detection systems, because the duration of the test is shorter than the other methods. The LRDP can meet the monitoring and precision regulatory requirements in a 10- or 24-h test. The other technologies typically require 24 to 72 h, and other than the LRDP, none of the permanently mounted in-tank systems have sufficient performance to perform a precision test.

6.5 Lessons Learned

In order to conduct a leak detection test with this technology, the tank must be isolated from the piping associated with the tank. Thus, it is important that all valves at the tank be completely sealed before a test is initiated. This is particularly important when conducting a precision test at 0.2 gal/h. Many of the valves at DoD facilities are double-block and bleed valves, which allow a visual check of the seal and a measurement of the flow across the valve if it does not seal. The monthly monitoring standards are sufficiently large in comparison to the performance of the LRDP that small valve leaks can be tolerated during a test without impacting the results. It is also important that any drainback of fuel into the tank has ceased before a test is initiated. It is for this reason that a 2-h waiting period was implemented. However, if drainback is not a problem, then no waiting period is required for the conduct of a leak detection test with a mass-based system like the LRDP.

6.6 End-User Issues

The LRDP is ready for commercialization. The drawings, specifications, and software screens are described in Appendices C and D of the final report [18]. The LRDP already has regulatory approval, and the evaluation conducted as a DEM/VAL at Point Loma has been submitted for approval by the NWGLDE in April 2001. Since this submittal parallels the previous submittal, no significant technical acceptance problems are anticipated. As of this publication date, the third-party evaluation is still under review by the NWGLDE.

At the request of NFESC, during this ESTCP project, a workshop was conducted by the Environmental Technology Evaluation Center (EvTEC) of the Civil Engineering Research Foundation (CERF) to introduce the technology and to describe the advantages of the system for regulatory compliance [20]. Technical experts and representatives from the petroleum industry, the Defense Energy Support Center (DESC), and the U. S. Air Force, Army, and Navy were present. The LRDP was also submitted for an R&D 100 award.

Vista Research, Inc., has commercialized the LRDP and is now offering products and services based on the LRDP implemented using a PLC in place of the remote test controller. Product description and product specification sheets are available (Appendix C of the final report [18]). Immediate commercialization of this technology has been possible, because industry was involved during the demonstrations and the bulk storage tank facilities have a real need to address. Some limited sales of the LRDP have already occurred. For example, the LRDP has been used to test other bulk USTs at Point Loma, other than Tank 175 used in the first DEM/VAL, to determine the integrity of these tanks. In addition, under a pre-production initiative with the Navy, the LRDP was recently installed in one of the 12,500,000-gal tanks at Red Hill for a third-party evaluation. The results of the evaluation are consistent with the results of the performance evaluation obtained at Point Loma [19]. If the LRDP is used to test 50,000-gal USTs or tanks with curved walls for regulatory compliance, another third-party evaluation will have to be conducted.

6.7 Approach to Regulatory Compliance and Acceptance

Two practical regulatory guidelines for using in-tank mass-based measurements in California were developed and recommended by NFESC and Vista Research (Options 7 and 10). Option 7 requires monthly monitoring tests with a system capable of detecting a leak between 1.0 and 2.0 gal/h with a $P_D \geq 95\%$ and a $P_{FA} \leq 5\%$, and a semi-annual precision test with a method capable of detecting a leak of 0.2 gal/h with the same P_D and P_{FA} as for the monthly monitoring test. Option 10 is similar to Option 7, except the monthly monitoring criteria is 0.3 to 1.0 gal/h, and the precision test need only be conducted annually. While the precision test requirement of 0.2 gal/h is stringent, it is achievable by the LRDP and for many tanks with only a single test. The monthly monitoring requirements of 0.3 to 1.0 gal/h or 1.0 to 2.0 gal/h are operationally practical and easily met by the LRDP.

The approach to regulatory requirement depends on the size of the tank to be tested as was discussed in Section 4.1.5. The main recommendation is to operate the system such that the regulatory requirements can be met with the lowest probability of false alarm. Given the choice, the monthly monitoring should be addressed using the largest target leak rate as possible less than 2.0 gal/h. This minimizes any minor system problems that might otherwise interfere with a test (i.e., a small flow across a valve).

7.0 References

1. J. W. Maresca, Jr. and J. W. Starr. "The LRDP System for Detection of Leaks in Bulk Storage Tanks." Final Report, prepared for the Naval Facilities Engineering Service Center, 110023rd Avenue, Port Hueneme, CA 93043-4370, prepared by Vista Research, Inc., 100 View Street, Mountain View, CA 94042, 25 March 1998.

2. W. Major, L. Karr, G. Warren, and J. Norbutas. "Red Hill Fuel Tank Leak Detection." Proceedings of the Seventh (1997) International Offshore and Polar Engineering Conference, Honolulu, Hawaii, Naval Facilities Engineering Service Center, Port Hueneme, California, 25-30 May 1997.

3. U.S. Environmental Protection Agency. "40 CFR 280 - Technical Standards and Corrective Action Requirements for Owners and Operators of Underground Storage Tanks." *Federal Register*, Vol. 53, No. 185, 23 September 1988.

4. California Water Resources Control Board. "Local Guidance Letters LG 151-2." 22 October 1999.

5. J. K. Wilcox. "Evaluation of the LRDP-10 on Bulk Field-Constructed Tanks: Final Report." Third-Party Evaluation Report, prepared for the Naval Facilities Engineering Service Center and Vista Research, Inc., prepared by Ken Wilcox Associates, Inc., 1125 Valley Ridge Drive, Grain Valley, MO 64029, 4 December 2000.

6. J. K. Wilcox. "Evaluation of the LRDP-10 on Bulk Field-Constructed Tanks: EPA Forms." Third-Party Evaluation EPA Forms, prepared for the Naval Facilities Engineering Service Center and Vista Research, Inc., prepared by Ken Wilcox Associates, Inc., 1125 Valley Ridge Drive, Grain Valley, MO 64029, 4 December 2000.

7. J. K. Wilcox. "Evaluation Update of the LRDP-24 on Bulk Field-Constructed Tanks: Final Report." Third-Party Evaluation Report, prepared for the Naval Facilities Engineering Service Center and Vista Research, Inc., prepared by Ken Wilcox Associates, Inc., 1125 Valley Ridge Drive, Grain Valley, MO 64029, 4 December 2000.

8. J. K. Wilcox. "Evaluation Update of the LRDP-24 on Bulk Field-Constructed Tanks: EPA Forms." Third-Party Evaluation EPA Forms, prepared for the Naval Facilities Engineering Service Center and Vista Research, Inc., prepared by Ken Wilcox Associates, Inc., 1125 Valley Ridge Drive, Grain Valley, MO 64029, 4 December 2000.

9. J. K. Wilcox. "Evaluation of the LRDP-10-n Bulk Field-Constructed Tanks: Final Report." Third-Party Evaluation Report, prepared for the Naval Facilities Engineering Service Center and Vista Research, Inc., prepared by Ken Wilcox Associates, Inc., 1125 Valley Ridge Drive, Grain Valley, MO 64029, 4 December 2000.

10. J. K. Wilcox. "Evaluation of the LRDP-10-n Bulk Field-Constructed Tanks: EPA Forms." Third-Party Evaluation EPA Forms, prepared for the Naval Facilities Engineering Service

Center and Vista Research, Inc., prepared by Ken Wilcox Associates, Inc., 1125 Valley Ridge Drive, Grain Valley, MO 64029, 4 December 2000.

11. J. K. Wilcox. "Evaluation Update of the LRDP-24-n on Bulk Field-Constructed Tanks: Final Report." Third-Party Evaluation Report, prepared for the Naval Facilities Engineering Service Center and Vista Research, Inc., prepared by Ken Wilcox Associates, Inc., 1125 Valley Ridge Drive, Grain Valley, MO 64029, 4 December 2000.

12. J. K. Wilcox. "Evaluation Update of the LRDP-24-n on Bulk Field-Constructed Tanks: EPA Forms." Third-Party Evaluation EPA Forms, prepared for the Naval Facilities Engineering Service Center and Vista Research, Inc., prepared by Ken Wilcox Associates, Inc., 1125 Valley Ridge Drive, Grain Valley, MO 64029, 4 December 2000.

13. National Work Group on Evaluation of Leak Detection Methods. "List of Leak Detection Evaluations for Underground Storage Tank Systems." Office of Underground Storage Tanks, U.S. Environmental Protection Agency, 7th Edition, April 2000.

14. U.S. Environmental Protection Agency. "Alternative Test Procedures for Evaluating Leak Detection Methods: Evaluation of Bulk Field Constructed Tanks." Region VII, Memorandum, March 1996.

15. W. R. Major, L. A. Karr, G. A. Hayter, and J. W. Maresca, Jr. "ESTCP Technology Demonstration Plan: Validation of the Low Range Differential Pressure (LRDP) Leak Detection System for Small Leaks in Bulk Fuel Tanks." Naval Facilities Engineering Service Center, Port Hueneme, California, 18 July 1988.

16. J. W. Maresca, Jr., "System and Method for Leak Detection in Liquid Storage Tanks." U. S. Patent No. 4,646,560, Vista Research, Inc., Palo Alto, California, 3 March 1987.

17. American Society of Testing Materials. "Standard Practice for Evaluating the Performance of Release Detection Systems for Underground Storage Tank Systems (ASTM E 1526 - 93)." in *Annual Book of ASTM Standards* (Philadelphia: American Society of Testing and Materials, May 1993.

18. L. A. Karr, W. R. Major, J. W. Maresca, Jr., J. W. Starr, and G. A. Hayter. "Validation of the Low Range Differential Pressure (LRDP) Leak Detection System for Small Leaks in Bulk Fuel Tanks." ESTCP Final Report. Naval Facilities Engineering Service Center, 1100 23rd Avenue, Port Hueneme, California 93043-4370 and Vista Research, Inc., 755 North Mary Avenue, Sunnyvale, California 94085, 25 April 2001.

19. L. A. Karr, W. R. Major, J. W. Maresca, Jr., M. J. Talhami, J. W. Starr, and R. F. Wise. "Pre-Production Initiative: Low Range Differential Pressure (LRDP) Leak Detection System - Red Hill Test Results." Final Report. Naval Facilities Engineering Service Center, 1100 23rd Avenue, Port Hueneme, California 93043-4370 and Vista Engineering Technologies, L.L.C., 8203 W. Quinault, Kennewick, Washington 99336, 31 July 2001.

20. Environmental Technology Evaluation Center (EvTEC). "Low Range Differential Pressure (LRDP) Leak Detection System Workshop Report." Workshop Report. Environmental Technology Evaluation Center (EvTEC), 1015 15th Street, Suite 600, Washington D.C. 20005-2605, June 2000.

8.0 Points of Contact

The points of contact for this project are presented in Table 15.

Table 15. Points of Contact

Point of Contact	Organization	Phone/Fax/Email	Role in Project
Leslie A. Karr, REM Program Manager	Naval Facilities Engineering Service Center (NFESC) 1100 23rd Avenue Port Hueneme, CA 93043-4370	voice: (805) 982-1618 fax: (805) 982-4304 e-mail: karrla@nfesc.navy.mil	Project Manager
William R. Major Project Engineer	Naval Facilities Engineering Service Center (NFESC) 1100 23rd Avenue Port Hueneme, CA 93043-4370	voice: (805) 982-1808 fax: (805) 982-4304 e-mail: majorwr@nfesc.navy.mil	Project Engineer
Dr. Vincent F. Hock Program Manager	U. S. Army Corps of Engineers Construction Engineering Research Laboratory (CERL) 2902 Nemark Drive Champaign, Illinois 61826	Voice: (217)373-6753 fax: (217)373-6732 e-mail: v-hock@cecer.army.mil	Project Engineer
Dr. Joseph W. Maresca, Jr. Vice President	Vista Research, Inc. 755 North Mary Avenue Sunnyvale, California 94086	voice: (408) 830-3306 fax: (408) 830-3399 e-mail: maresca@vrinc.com	Technical Director, Industry Partner
James W. Starr, P. E. Staff Engineer	Vista Research, Inc. 139 Glendale Avenue Edison, New Jersey 08817	Voice: (732) 777-2100 Fax: (732) 777-9495 e-mail: jstarr@vrinc.com	Project Engineer
Gary A. Hayter Sr. Research Engr	Vista Research, Inc. 755 North Mary Avenue Sunnyvale, California 94086	voice: (408) 830-3300; fax: (408) 830-3399 e-mail: ghayter@vrinc.com	Project Engineer
Dr. H. Kendall Wilcox President	Ken Wilcox Associates, Inc. 1125 Valley Ridge Drive Grain Valley, MO 64029, USA	voice: (816) 443-2494 fax: (816) 443-2495 e-mail: kwilcox@kwaleak.com	Third-Party Evaluator
Col Patrick L. Fink U. S. Air Force	Randolph Air Force Base San Antonio, TX	voice: (210) 652-6375	DEM/VAL Liaison
George E. Cook, III Director, Fuel Farm	Supply Department Code 199, Building 426 NAS North Island P. O. Box 357039 San Diego, CA 92135-7039	Voice: (619) 545-8841 fax: (619) 545-8841	DEM/VAL Liaison
Clarence Wilson Director, Fuel Farm	Defense Energy Office, Los Angeles 3171 North Gaffey Street San Pedro, CA 90731-1099	voice: (310) 335-3090 ext. 404 fax: (310) 335-	DEM/VAL Liaison
LCDR R. C. Griffin, SC, USN Point Loma Site Director	FISC San Diego Point Loma Fuel Terminal 937 N. Harbor Drive, STE 480 San Diego, CA 92132-0480	voice: (619) 553-1312 fax: (619) 553-4877 e-mail: Rowdy_Griffin@sd.fisc.navy.mil	DEM/VAL Liaison
Stephen L. Frey Fuels Terminal Director	FISC San Diego Point Loma Fuel Terminal 937 N. Harbor Drive, STE 480, Code 701 San Diego, CA 92132-0480	voice: (619) 553-1314 fax: (619) 553-4877 Stephen_L_Frey@sd.fisc.navy.mil	DEM/VAL Liaison
Dale Kiefer Environmental Division Head	Hunter Army Airfield Ft Stewart, GA 31314	voice: 912-767-2010	DEM/VAL Liaison
Terry Nierenhausen	Hunter Army Air Field 98 South Middleground Road, Building 1216 Savannah, GA 31409	voice: (912) 352-5535	DEM/VAL Liaison

William Middleton	Defense Energy Office – Los Angeles Defense Energy Supply Center (DESC) John J. Kingman Road, Suite 4950 Fort Belvoir, VA22060-6222	voice: (702) 767-8313 fax: (703) 767-8331 e-mail: wmiddleton@desc.dla.mil	DEM/VAL Liaison
Brian Rustia	EvTEC 1015 15th Street, NW, Suite 600 Washington D.C. 20005-2605	voice: (202) 842-0555 fax: (202) 842-2605	CERF Workshop
Heather Warkentien	EvTEC 1015 15th Street, NW, Suite 600 Washington D.C. 20005-2605	voice: (202) 842-0555 fax: (202) 842-2605	CERF Workshop
Russ Brauksieck New York DEC	New York State Department of Environmental Conservation 50 Wolf Road, Room 360 Albany, NY 12233-3750	voice: (518) 457-4351 fax: (518) 457-4332 e-mail: rxbrauks@gw.dec.state.ny.us	NWGLDE, Chairman Bulk USTs, New York Regulator
Beth DeHaas Maine DEP	Maine Department of Environmental Protection Statehouse Station No. 17 Augusta, ME 04333	voice: (207) 287-2651 fax: (207) 287-7826 e-mail: beth.dehaas@state.me.us	NWGLDE, Bulk USTs, Maine Regulator
Shahla Farahnak California SWRCB	California State Water Resource Board Division of Clean Water Program P. O. Box 944212 Sacramento, CA 94244-2120	voice: (916) 227-4320 fax: (916) 227-4349 e-mail: farahnas@gwgate.swrcb.epa.gov	NWGLDE, Bulk USTs, California Regulator
John Reeder Florida DEP	Florida Department of Environmental Protection 3804 Coconut Palm Drive Tampa, FL 33619-8318	voice: (813) 744-6100 ext. 472 fax: (813) 744-6125 e-mail: jon.reeder@dep.state.fl.us	NWGLDE, Florida Regulator
John Kneece South Carolina DHEC	South Carolina Department of Health and Environmental Control 2600 Bull Street Columbia, SC 29201	voice: (803) 898-4364 fax: (803) 898-4330 e-mail: kneeceje@colum26.dhec.state.sc.us	NWGLDE, South Carolina Regulator
Curt D. Johnson Alabama DEM	Alabama Department of Environmental Management P. O. Box 301463 Montgomery, AL 36130-1463	voice: (334) 271-7986 fax: (334) 270-5631 e-mail: cdj@adem.state.al.us	NWGLDE, Chairman, Alabama Regulator

Appendix A

Results of the Performance Evaluation for Different Implementations of the LRDP-10 and LRDP-24 Leak Detection Systems

Table A-1. Formula to Compute the Threshold and Target Leak Rate as a Function of Tank Diameter for the LRDP-10

Method	Tank Diameter	Target Leak Rate
(Probability of detection of 95% with a probability of false alarm of 5%) Version 1.2a	*For tank diameters less than 51.3 ft* *For tank diameters (D in ft) up to 193.7 ft* *For tank diameters* $D = [2{,}635.0 \cdot (n)^{0.5}]^{0.5}$ *(LRDP-10-n)*	0.20 gal/h $(3.14 \cdot (D \cdot 0.5)^2/11{,}786) \cdot 1.139$ gal/h 0.20 gal/h (average of $1 < n \leq 12$ tests)
(Probability of detection of 95% with a probability of false alarm of 0.29%) Version 1.1a	*For tank diameters (D in ft) up to 193.7 ft* *For tank diameters* $D = [1{,}817.3 \cdot (n)^{0.5}]^{0.5}$ *(LRDP-10-n)*	$(3.14 \cdot (D \cdot 0.5)^2/11{,}786) \cdot 1.653$ gal/h 0.20 gal/h (average of $1 < n \leq 12$ tests)
(Probability of detection of 95% with a probability of false alarm of <0.15%) Version 1.0a	*For tank diameters (D in ft) up to 193.4 ft* *For tank diameters (D in ft) up to 193.4 ft*	$(3.14 \cdot (D \cdot 0.5)^2/11{,}786) \cdot (2.0-0.569)$ gal/h $(3.14 \cdot (D \cdot 0.5)^2/11{,}786) \cdot (3.0-0.569)$ gal/h

Table A-2. Formula to Compute the Threshold and Target Leak Rate as a Function of Tank Diameter for the LRDP-24

Method	Tank Diameter	Target Leak Rate
(Probability of detection of 95% with a probability of false alarm of 5%) Version 1.2a	*For tank diameters less than 66.0 ft* *For tank diameters (D in ft) up to 193.7 ft* *For tank diameters* $D = [4{,}349.7 \cdot (n)^{0.5}]^{0.5}$ *(LRDP-24-n)*	0.20 gal/h $(3.14 \cdot (D \cdot 0.5)^2/11{,}786) \cdot 0.69$ gal/h 0.20 gal/h (average of $1 < n \leq 12$ tests)
(Probability of detection of 95% with a probability of false alarm of 0.48%) Version 1.1a	*For tank diameters (D in ft) up to 193.7 ft* *For tank diameters* $D = [3{,}172.4 \cdot (n)^{0.5}]^{0.5}$ *(LRDP-24-n)*	$(3.14 \cdot (D \cdot 0.5)^2/11{,}786) \cdot 0.946$ gal/h 0.20 gal/h (average of $1 < n \leq 12$ tests)
(Probability of detection of 95% with a probability of false alarm of <0.003%) Version 1.0a	*For tank diameters (D in ft) up to 193.4 ft* *For tank diameters (D in ft) up to 193.4 ft*	$(3.14 \cdot (D \cdot 0.5)^2/11{,}786) \cdot (2.0-0.345)$ gal/h $(3.14 \cdot (D \cdot 0.5)^2/11{,}786) \cdot (3.0-0.345)$ gal/h